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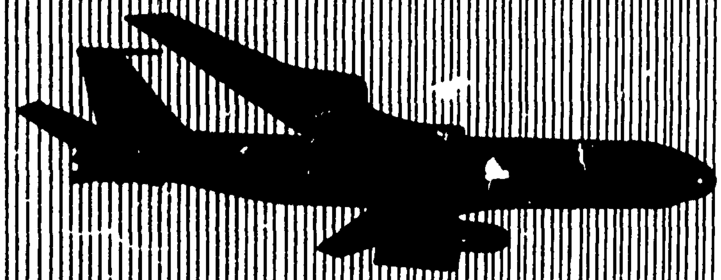

EVALUATION STUDY OF TRANSPORT VEHICLES

D6 - 2067

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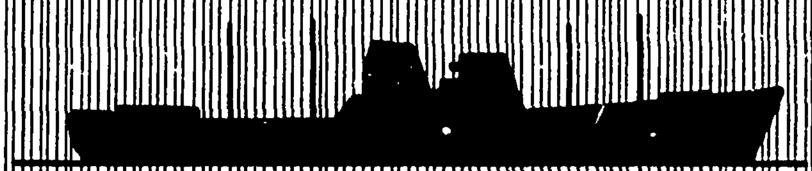

Final Report for Contract NO_w - 63 - 0804C

THE BOEING COMPANY
AIRPLANE DIVISION
P. O. BOX 707 · RENTON, WASHINGTON

EVALUATION STUDY OF TRANSPORT VEHICLES

D6-2067

FINAL REPORT FOR CONTRACT NO_W-63-0804C

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Data are shown on efficiency parameters such as vehicle L/D and cruise speed and on a cost parameter defined as the total transport system cost for each of the selected vehicles. A section is presented on operational factors which includes reliability, utilization, useful life and environment. This operational material is generally qualitative and is not necessarily limited to vehicles of this study.

The information is presented in data plots for ease of comparison and is summarized in tables.

Most coverage is given to current and possible future transport aircraft and ships. Covered in less detail are such vehicles as airships, helicopters, ground effect machines, hydrofoils and submarines.

The vehicles were chosen on the basis of being representative of their respective time periods and for showing the effect of changing a major design variable such as type of engine. The data for current vehicles were taken from flight manuals or other operating information. Data for future vehicles were generated in this study or were obtained from published information on selected vehicles.

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ACKNOWLEDGEMENTS

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SYMBOL LIST

a	Turbofan engine bypass ratio = $\frac{\text{Wt flow of air passing fan nozzle}}{\text{Wt flow of air passing primary nozzle}}$
bbl	Barrel, 6.63 barrels of fuel oil weigh one long ton.
C_f	Equivalent 3-dimensional friction coefficient
F_N/δ	Engine net thrust (lbs)/atmospheric pressure ratio
f	Equivalent drag area, square feet. Equal to $C_f \times S_w$
GW	Gross Weight or gross displacement, lbs, short tons, or long tons as noted
HP	Horsepower, brake HP for reciprocating engines; equivalent shaft HP for turboprop engines. Values quoted for aircraft are maximum dry sea level static rating
h/b	Ratio of height above water to span, measured at aircraft 1/4 MAC
L/D	Lift/drag ratio. Values quoted are at the average cruise point. See $\triangleright$1, page 11.
LFC	Laminar Flow Control
LOBOY	A generic term applied to certain winged aircraft which fly in ground effect to reduce induced drag.
L.T.	Long ton = 2,240 lbs
MAC	Mean Aerodynamic Chord
M L/D	The product, Mach No. x L/D
M.T.	Measurement ton = 40 cubic feet of cargo volume
N. Mi./lb	Vehicle nautical mile/lb fuel consumed
O.W.E.	Operating Weight Empty, lbs, short tons, or long tons as noted. For aircraft see page 200. For ships = weight of steel + weight of machinery + weight of outfit + weight of provisions, stores, crew and effects, and dunnage.
P	General symbol to indicate total dry rated power available in terms of HP, ESHP, or thrust for reciprocating, turboprop, or turbofan engines respectively.

P/L	Payload or cargo deadweight, lbs, short tons, or long tons as noted.
POL	Petrol, oil and lubricant
R	Range, nautical miles
S	Wing area, square feet
SHP_N	For marine installations, total normal shaft horsepower.
S_w	Airplane wetted area, square feet.
$S_{f_{T.O.}}$	Takeoff field length, feet.
$sfc/\sqrt{\theta}$	Specific fuel consumption/square root of atmospheric temperature ratio
S.T.	Short ton = 2,000 pounds
T	Thrust, pounds
V_{cru}	Cruise speed, knots

W_{STRU}	Structural weight, pounds, short tons, or long tons as noted For aircraft see page 200 For ships W_{STRU} = Weight of steel unless otherwise noted.
W_{PP}	Powerplant weight, pounds, short tons or long tons as noted For aircraft see page 200 For ships W_{PP} = Weight of machinery unless otherwise noted.
W_{F_U}	Weight of fuel used, pounds, short tons or long tons as noted W_{F_U} = total fuel less reserve fuel
$\eta_{overall}$	Efficiency parameter defined as: $\frac{\text{work/unit time done on vehicle}}{\text{work equivalent fuel input/unit time}}$

1.0 INTRODUCTION

The purpose of this report is to present information in handbook form on selected transport vehicles. It is expected that the report will be useful in providing a background for future comparative studies.

Material is presented in three basic areas:

1. Data related to the vehicle technical efficiency. (Section 3.0)
2. Data related to vehicle operation. (Section 4.0)
3. Data related to vehicle cost and operation on a selected intercontinental mission. (Section 5.0)

Vehicles selected for inclusion in the study include aircraft, ships, underwater craft and several vehicles which are new and different - termed innovations. The vehicles are primarily those used for intercontinental transport. Several aircraft and ships which do not fit this classification are included to provide an end point to the data curves.

The format of the efficiency data presentation is generally similar to that followed by Gabrielli and Von Karman in their paper "What Price Speed?", although a much more comprehensive coverage is given to the selected vehicles.

Operational data are presented in narrative style. Each of the several items categorized as "operational" is discussed and examples are shown, where applicable. Because of the nature of the subject, this section is necessarily less quantitive than either Sections 3 or 5.

Cost data are shown in tables and curves for the study vehicles, each used in a typical intercontinental mission. The intent is more to present engineering data than to complete an operational research study. Because operational costs are connected with mission considerations it was necessary to define a general mission. Ground rules and assumptions are discussed in Sections 4.6 and 5.3.

To provide as complete coverage as possible for transport vehicles in the time period between now and 20 years hence, several classified vehicles have been chosen. Efficiency parameter data on these classified vehicles is contained in a confidential supplement to this report, D6-2068, "Evaluation Study of Transport Vehicles - Supplement."

2.0 DISCUSSION

The most significant problem confronting the designer when evaluating advancements in the state-of-the-art is to separate that which is feasible from that which is desirable.

It is helpful to recognize that successful vehicles are necessarily an integration of technical advancement and economic situation. Viewed in retrospect these historical integrations of technical, operational and economic facts are useful for making comparisons with current engineering possibilities.

The three major sections of this report are presented with this use in mind. The current vehicles for which data are shown were picked on the basis that

1. *they were representative of a certain time period or vehicle group and that*
2. data were available in sufficient detail to allow adequate description. Future vehicles were chosen on the basis of what is possible if the current state-of-the-art is projected 20 years into the future.

2.1 DEFINITION OF STUDY VEHICLE CHARACTERISTICS

2.1.1 TRANSPORT AIRCRAFT

Aircraft selected for the study are listed in Table 1. They are typical transport aircraft which operate currently, together with some which may operate in the next 20 years. Several of the current aircraft were brought into service as much as 20 years ago. This provides approximately a 40 year spread between the oldest aircraft presented and the most advanced projections.

The current aircraft generally are well known and most readers will be well acquainted with them. For the benefit of other readers the characteristics listed in Table 1 will serve to identify each of the plotted points in Section 3.2

Ten aircraft designed specifically for this study are identified with Boeing model numbers 742-302 through 742-311. These aircraft are typical of state-of-the-art advances which could take place in the next 20 years. Model

Table 1 Aircraft Characteristics

AIRCRAFT	YEAR ENTER SERVICE	GROSS WEIGHT (LB)	WING SPAN (FT)	WING AREA (SQ FT)	NO. ENGINES	ENGINE TYPE	TOTAL INSTALLED STATIC POWER OR THRUST	AVG. CRU TOTAL FUEL FLOW (LB/HR)	CRUISE SPEED (KTS)	REMARKS
C-54G	1945	69,000	117.5	1457	4	P & W R-2000-9	5800 HP	1,386	176	
JRM-2	1946	165,000	200.0	3686	4	P & W R-1360-4	12000 HP	2,142	150	
C-118A	1952	107,000	117.5	1463	4	P & W R-2800-52W	8800 HP	1,881	217	
C-124C	1953	185,000	174.1	2506	4	P & W R-4360-63A	13600 HP	3,239	182	
C-133A	1957	275,000	179.7	2573	4	P & W T34-P-7WA	24000 ESHP	8,200	260	
CL-44D-4	1961	205,000	142.3	2075	4	R-R TYNE 12 MARK 515	22920 ESHP	4,668	321	
C-135B	1962	277,500	130.8	2433	4	JT3D-3	72000 LBS	11,132	457	
C-130E	1962	155,000	132.6	1745	4	Allison T56-A-7	16200 LBS	4,253	292	
707-320C	1963	328,000	145.7	2942	4	JT3D-3B	72000 LBS	12,440	466	
L-300	1965	318,000	160.1	3228	4	JT3D-8A	84000 LBS	11,508	435	
742-302	1973	650,000	250.0	5630	4 T'PROP 3 T'FAN	1	30000 ESHP 69000 LBS	3,627	183	LOBOY - 200,000 lb P/L-8,800 N.MI.
-303	1973	565,000	232.5	4875	4 T'PROP 2 T'FAN	1	28000 ESHP 58000 LBS	3,492	189	LOBOY - 200,000 lb P/L-6,500 N.Mi.
-304	1973	830,000	288.0	9750	4 T'FAN + 4 COMP	2	166000 LB	14,950	420	LFC - 200,000 lb P/L-6,000 N.MI.
-305	1973	672,000	203.0	5166.2	6	a = 3 T'FAN	134400 LB	21,645	434	200,000 lb P/L-3,800 N.MI.
-306	1973	1,340,000	284.0	10307.7	6	a = 3 T'FAN	268000 LB	38,558	437	400,000 lb P/L-3,980 N.MI.
-307	1983	651,000	200.0	5007.7	6	a = 3 T'FAN	130200 LB	19,211	430	200,000 lb P/L-3,960 N.MI.
-308	1983	1,310,000	284.0	10076.9	6	a = 3 T'FAN	262000 LB	36,692	430	400,000 lb P/L-4,200 N.MI.
-309	1973	650,000	266.0	5909.1	6	a = 5 T'FAN	122640 LB	14,283	344	200,000 lb P/L-3,720 N.MI.
-310	1983	588,000	253.0	5345.5	6	a = 15 REGEN T'FAN	125106 LB	9,676	344	200,000 lb P/L-3,920 N.MI.
742-311	1973	356,000	148.2	2738.5	4	a = 3 T'FAN	73744 LB	11,176	431	100,000 lb P/L-4,200 N.MI.
748B-15	1968	600,000	206.8	5000	6	P & W JT3D-8B	138000 LB	22,973	446	160,000 lb P/L-2,785 N.MI.

1 CRUISE: REGEN T'PROP, TAKEOFF: REGEN T'PROP + T'FAN

2 BYPASS RATIO 5 T'FAN + LFC BLEED & BURN SUCTION COMPRESSOR

748B-15 is also a study aircraft. It is one of many configurations which have been considered for the (now) CX-HLS mission.

Data are presented for these study aircraft not as a prediction of what will occur in the future nor is their presence in this study indicative of particular current interest. Rather, each was chosen as being representative of one or more engineering advances which may be technically feasible. As such, each configuration is worthy of comparison with other current and future aircraft.

A fairly conservative approach was taken in defining these future aircraft. Description of the design method is included in Section 7.

2.1.2 TRANSPORT SHIPS

Transport ships, selected for the study, are listed in Table 2. In line with the nature of the study, they are mostly dry-cargo transports. A few tankers are included for comparison. The selection provides a representative cross-section of vehicles and power plants. It will be noted that most of the current dry-cargo ships were launched 15 to 20 years ago. Exceptions are, the Mariner Class ships which were introduced in 1952, and the roll-on/roll-off designs seen in the last 4 years.

The increase in ship size and speed with time is characteristically much slower than for aircraft. The 742-320S, -321S ships designed for this study, reflect this conservatism. These ships are described in Section 7.2 and in Ref. 26. The large current tankers included show perfectly the increase in L/D possible with very large (long) ships operated at moderate speeds, to take advantage of the possible reduction in wave making drag.

2.1.3 UNDER WATER TRANSPORT

A number of studies have been completed, in recent years, to evaluate submarine transports. Refs. 31 and 33 are samples of this work. Several study configurations for these submarine transports have been included in the efficiency section of this report. They are defined in Table 3. The actual operational and cost data for submersibles, to date, is entirely for Navy strategic or tactical missions. The lack of

Table 2 Ship Characteristics

SHIP	YEAR ENTER SERVICE	GROSS DISPLACE-MENT (L.T.)	LENGTH BETWEEN PERP. (FT)	BEAM (FT)	ENGINE TYPE	TOTAL INSTALLED POWER SHP_N	FUEL FLOW @ SHP_N (BBL/DAY)	SEA SPEED (KTS)
C3-S-A2	1942	17615	462.0	69.5	STEAM TURBINE	8500	376	16.5
C1A	1942	11085	390.0	60.0	STEAM TURBINE	4000	176	14.0
C2-S-AJ1	1943	14945	435.0	63.0	STEAM TURBINE	6000	258	15.5
VC2-S-AP3	1944	15210	437.0	62.0	STEAM TURBINE	8500	329	16.5
C1-M-AV1	1944	8265	324.0	50.0	DIESEL	1700	63	10.5
C4-S-1[illegible]	1952	21093	528.0	76.0	STEAM TURBINE	17500	647	20.3
C3-ST-14a	1958	18286	465.0	78.0	STEAM TURBINE	11220	478	18.0
C4-S-57a	1963	21053	529.0	75.0	STEAM TURBINE	16500	625	20.5
C4-ST-67a	1964	21700	499.5	83.0	STEAM TURBINE	17500	702.5	20.0
T2-SE-A1	1942	21748	510.0	68.0	TURBO-ELEC.	6000	271	14.5
S.S. MANHATTAN	1962	137068	892.0	132.0	STEAM TURBINE	39000	1440	17.7
MEDIUM TANKER	1955	49660	677.0	93.0	STEAM TURBINE	20000	738	18.0
742-320S	1975	24000	598.0	76.0	STEAM TURBINE	24000	852	23.5
742-320S NUC	1975	24000	598.0	76.0	NUCLEAR	24000	---	23.5
742-321S	1985	45000	750.0	106.0	STEAM TURBINE	66000	2215	25.0
742-321S NUC	1985	45000	750.0	106.0	NUCLEAR	66000	---	25.0

any available information for a general logistic mission precluded their use in Sections 4 and 5. In addition, most authoritative writers indicate that the design problems for submarine transport outweigh the operational advantages to such an extent that even in 20 years' time their appearance is doubtful. For the present these vehicles are categorized as engineering possibilities and economic improbabilities.

2.1.4 INNOVATION TRANSPORT CRAFT

From time to time, vehicles are presented which can only be categorized as innovations to the transport field. They are to a greater or lesser extent technically feasible. The economic justification is often less apparent than the engineering feasibility and their development is terminated short of completion.

Vehicles of Table 4 are in part of this kind. The airships are included for their historical interest and to complete the vehicle comparisons against speed and calendar years.

While the helicopter has entrenched itself firmly in certain short range mission areas it does not fit the role of transport aircraft in the same sense as a fixed wing aircraft. For this

Table 3 Submarine Characteristics

SUBMARINE	YEAR ENTER SERVICE	GROSS DISPLACEMENT (L.T.)	BEAM (FT)	ENGINE TYPE	TOTAL INSTALLED POWER SHP_N	SEA SPEED (KTS)
TANKER A	1980	41800	80.0	NUCLEAR	27400	20.0
TANKER B	1980	101400	80.0	NUCLEAR	218000	37.4
TANKER C	1980	48200	78.74	NUCLEAR	40000	22.0

Table 4 Innovation Craft Characteristics

VEHICLE	VEHICLE TYPE	YEAR ENTER SERVICE	GROSS WEIGHT OR DISPLACEMENT	LENGTH BETWEEN PERP. (FT)	BEAM (FT)	ENGINE TYPE	TOTAL INSTALLED POWER	FUEL FLOW	SPEED (KTS)
742-322S	HYDROFOIL	1970	1060 L.T.	235	52	GAS TURBINE	24200 HP	942 bbl/day	40.0
90 TON P/L	GEM	1970	280000 LB	-	-	GE T-64	11200 ESHP	4519 lb/hr	40.0
15 TON P/L	GEM	1970	62270 LB	-	-	GE T-64	5400 ESHP	2564 lb/hr	40.0
VERTOL HC-1B	HELICOPTER	1962	33000 LB	-	-	LYCOMING T-55	5490 ESHP	2338 lb/hr	130.0
ZMC-2	AIRSHIP	1929	11900 LB	-	-	WRIGHT J-5	440 HP	77 lb/hr	40.0
MACON	AIRSHIP	1933	403000 LB	-	-	MAYBACH V12	4480 HP	784 lb/hr	50.0
ZPG-2	AIRSHIP	1954	66800 LB	-	-	WRIGHT R-1300-2A	1600 HP	195 lb/hr	40.0

reason it is included here rather than in Table 1.

The same comment applies to the hydrofoil ship, as compared to the displacement ship.

A large number of Ground Effect Machine configurations have been proposed and several are now operating. While many claims have been made, they are still, at best, innovations. In the interest of realism and economy of effort in this study only two GEM's, of Ref. 23, are presented.

Efficiency data, for the airship, helicopter, hydrofoil ship and GEM, are presented as completely as possible. Operational and cost parameter data are omitted because of their paucity or because of the unreasonable effort required to make it compatible with other data.

In addition, a limited amount of efficiency data is presented in Section 3.2.7 for certain marine innovations. These data are less complete than for the other innovations but are shown, in limited form, for their interest.

3.0 EFFICIENCY PARAMETER DATA

3.1 DEFINITION OF PARAMETERS OF INTEREST

The efficiency parameters are defined by the data plots (Figs. 3 through 71) of this section. Tables 5 and 6 are provided to summarize these data and to provide greater accuracy than is possible to read from the plots. In some of the plots, due to the large variation in the parameter value, a compromise had to be made between choosing easily read scale values and omitting, from the plot, the extreme values. This results in some vehicle parameters not appearing in the plotted data.

Taken singly or in combination these parameters define each vehicle's aerodynamic (or hydrodynamic), propulsive, and structural efficiency. The data have been derived from T.O.'s and SAC charts for the military airplanes. Commercial airplane data were taken from manufacturer's performance manuals and detail specifications. Ship data were obtained from MSTS and MarAd documents. Data for vehicles designed in the course of this study were developed using standard design information and techniques.

Aircraft and ship designers commonly use terms which are unique to their own fields. Insofar as possible, ship building parameters have been defined in aircraft terms for these plots. An explanation is given where common definitions are not possible.

The data are presented in five basic groups:

I. data plotted vs. V_{cru}

II. data plotted vs. year enter service

III. data plotted vs. $P/L \times V_{cru}$ (P/L is taken as the maximum permissible value)

IV. data plotted vs. $P/L \times R$ (the product is taken as the maximum permissible value)

V. A comparison of takeoff field length for the aircraft

In Group V, takeoff field length is plotted, together with $\frac{P/L}{GW}$ and L/D, vs. V_{cru} and year entered service. In all cases the field length shown is for military critical field length at maximum takeoff weight.

For Groups I-IV the following parameters are plotted on the ordinate scale:

	Parameter	Comment
(1)	Year Enter Service	Not Shown for Group II
(2)	L/D	1 The value shown is for the average cruise point. It is somewhat less than the maximum value for several of the vehicles.
(3)	M L/D	1 Aircraft terminology. Not significant to ship performance and not shown for marine vehicles.
(4)	$\eta_{overall}$	1 $= \dfrac{\text{Work done on the vehicle/unit time}}{\text{Work equivalent fuel input/unit time}}$
(5)	$\eta_{overall} \times L/D$	1 This is a measure of the total vehicle efficiency.
(6)	$\frac{N.Mi.}{LB}$ (fuel)	1 Not shown for Groups III and IV
(7)	$P/L \times \frac{N.Mi.}{LB}$	1 Not shown for Groups III and IV
(8)	$\frac{P/L}{GW}$	For ships, P/L is generally referred to as cargo dead weight.
(9)	$\frac{OWE}{GW}$	See the symbol list for the meaning of this term for marine vehicles.
(10)	$\frac{P/L}{OWE}$	
(11)	$\frac{W_{stru}}{GW}$	This is a reasonable measure of the vehicles' structural efficiency when interpreted in the light of vehicle capability and design load factor.
(12)	$\frac{W_{pp}}{GW}$	
(13)	$\frac{W_{F_U}}{GW}$	2
(14)	$\frac{W_{pp} + W_{F_U}}{GW}$	2
(15)	$\frac{W_{pp} + W_{F_U}}{P/L}$	2
(16)	$\frac{W_{pp}}{P}$	Not shown for Groups III and IV
(17)	$\frac{P}{GW}$	Not shown for Groups III and IV
(18)	$\frac{P}{GW} \times V_{cru}$	Not shown for Groups III and IV

(19) $\frac{P}{P/L \times V_{cru}}$ — Not shown for Groups III and IV

(20) $\frac{P/L \times V_{cru}}{\text{Work equivalent fuel input per unit time}}$ — [1] Not shown for Groups III and IV

[1] This parameter is defined at the average cruise point. For aircraft this is taken to be 1/2 the range at the break in the P/L-Range curve. For ships it is arbitrarily set at 4000 N.Mi. Range does not have a strong influence on this parameter for ships.

[2] W_{F_U} is defined at the break in the P/L-R curve for aircraft. For ships it is arbitrarily set at 4000 N. Mi.

Most of these parameters will be familiar to the reader. A definition for each is included in the symbol list. Discussion on those which may be ambiguous or unfamiliar is included here.

$\eta_{overall}$ is defined as the ratio, work done on the vehicle to work equivalent fuel input. The work done per unit time = drag x velocity = $\frac{W}{L/D} \times V$.

The work input to the system/unit time = fuel flow x heat content x Joule's constant (778 FT-LB/BTU)

$\eta_{overall} \times L/D$ reduces to $\frac{W \times V}{\text{Work input/unit time}}$

$\frac{N. Mi.}{LB}$ This aircraft performance parameter varies inversely with vehicle size. It is most useful in comparing vehicles of the same payload and range capability.

$P/L \times \frac{N. Mi.}{LB}$ Dimensionally this parameter is useful work per pound fuel expended.

Items (8) through (12) are the usual vehicle weight fractions.

Item (13) is the fuel fraction at design payload and range.

Items (16) through (19) define the power or thrust characteristics for each of the vehicles. The basically different rating systems for turbofan and turboprop or piston aircraft engines preclude the use of common terminology. The respective symbols are defined in the symbol list.

$\frac{P/L \times V_{cru}}{\text{Work equivalent fuel input per unit time}}$ This parameter compares the useful work output with the work equivalent input per common time unit.

Table 5 Aircraft Efficiency Parameter Data

VEHICLE	IDENTIFICATION	YEAR ENTER SERVICE	L/D	M L/D	$\eta_{OVERALL}$	$\eta_{OVERALL} \times L/D$	$\frac{N.MI.}{lb}$	$P/L \times \frac{N.MI.}{lb}$	$\frac{P/L}{GW}$	$\frac{OWE}{GW}$	$\frac{P/L}{OWE}$	$\frac{W_{STRU}}{GW}$
								$\frac{ST\text{-}N.MI.}{lb}$				
Airplane	C-54G	1945	14.6	3.97	.242	3.53	.1266	1.22	.279	.584	.478	.283
Airplane	JRM-2	1946	17.1	3.91	.262	4.49	.0683	1.61	.285	.517	.552	.299
Airplane	C-118A	1952	17.8	6.08	.268	4.78	.1110	1.59	.267	.509	.525	.243
Airplane	C-124C	1953	17.2	4.83	.241	4.16	.0551	1.52	.299	.568	.526	.308
Airplane	C-133A	1957	17.5	7.57	.189	3.31	.0303	1.47	.353	.427	.828	.285
Airplane	CL-44D-4	1961	18.1	9.71	.289	5.24	.0682	2.19	.314	.442	.709	.298
Airplane	C-135B	1962	17.0	13.41	.242	4.12	.0394	1.71	.312	.391	.798	.236
Airplane	C-130E	1962	15.5	7.51	.257	3.99	.0650	1.46	.290	.471	.616	.254
Airplane	707-320C	1963	17.6	14.18	.250	4.41	.0352	1.68	.291	.410	.710	.249
Airplane	L-300	1965	16.7	12.62	.263	4.39	.0366	[illegible]55	.267	.407	.655	.265
Airplane	742-302	1973	34.8	9.64	.345	12.00	.0503	5.03	.308	.385	.798	.266
Airplane	742-303	1973	32.8	9.35	.351	11.50	.0537	5.37	.354	.402	.881	.275
Airplane	742-304	1973	34.2	24.97	.248	8.49	.0267	2.67	.241	.461	.522	.377
Airplane	742-305	1973	20.3	15.21	.264	5.36	.0205	2.05	.298	.396	.752	.314
Airplane	742-306	1973	21.2	15.65	.266	5.64	.0110	2.20	.299	.400	.746	.330
Airplane	742-309	1973	24.3	14.16	.250	6.07	.0235	2.35	.308	.422	.730	.335
Airplane	742-307	1983	20.4	14.82	.266	5.45	.0218	2.18	.30[illegible]	.331	.807	.302
Airplane	742-308	1983	21.5	15.55	.266	5.70	.0114	2.26	.305	.379	.805	.320
Airplane	742-310	1983	23.3	13.48	.354	8.26	.0346	3.46	.340	.446	.763	.339
Airplane	742-511	1973	19.2	14.35	.263	5.05	.0375	1.88	.281	.370	.759	.276
Airplane	748B-15	1968	16.8	12.95	.251	4.21	.0182	1.46	.267	.450	.593	.344
Helicopter	VERTOL HC-1B	1962	NA	-	-	-	.0556	.31	.333	.525	.610	.249
Ground effect machine	90 Ton P/L	1970	12.3	0.75	.083	1.02	.0089	.80	.644	.307	2.096	.247
Ground effect machine	15 Ton P/L	1970	8.6	0.52	.045	0.39	.0156	.23	.482	.390	1.236	.382
Airship	ZMC-2	1929	11.2	0.68	.211	2.36	.5159	.34	.109	NA	-	NA
Airship	MACON	1933	39.6	3.01	.245	9.73	.0637	2.91	.227	NA	-	NA
Airship	ZPG-2	1954	25.1	1.53	.208	5.22	.2058	.71	.103	.733	.141	.440

$\eta_{OVERALL}$	$\eta_{OVERALL} \times L/D$	$\frac{N.Mi.}{lb}$	$P/L \times \frac{N.Mi.}{lb}$	$\frac{P/L}{GW}$	$\frac{OWE}{GW}$	$\frac{P/L}{OWE}$	$\frac{W_{STRU}}{GW}$	$\frac{W_{PP}}{GW}$	$\frac{W_{FU}}{GW}$	$\frac{W_{PP}+W_{FU}}{GW}$	$\frac{W_{PP}+W_{FU}}{P/L}$	$\frac{W_{PP}}{P}$	$\frac{P}{GW}$	$\frac{P}{GW \times V_{CRU}}$	$\frac{P}{P/L \times V_{CRU}}$	$\frac{P/L \times V_{CRU}}{WORK}$
			$\frac{ST\text{-}N.Mi.}{lb}$									$\frac{lb}{F}$	$\frac{P}{lb}$	$\frac{P}{ST\text{-}KNOT}$	$\frac{P}{ST\text{-}KNOT}$	EQUIV. INPUT
.242	3.53	.1266	1.22	.279	.584	.478	.283	.172	.123	.295	1.056	2.039	.084	.951	3.408	1.053
.262	4.49	.0683	1.61	.285	.517	.55	.299	.127	.177	.304	1.068	1.752	.073	.970	3.393	1.447
.268	4.78	.1110	1.59	.267	.509	[illegible]	.243	.153	.201	.354	1.324	1.860	.082	.757	2.830	1.437
.241	4.16	.0551	1.52	.299	.568	.526	.308	.146	.120	.266	.892	1.987	.074	.808	2.704	1.332
.189	3.31	.0303	1.47	.353	.427	.828	.285	.070	.198	.268	.759	.804	.087	.671	1.900	1.310
.269	5.24	.0682	2.19	.314	.442	.709	.298	.065	.220	.285	.907	.583	.112	.696	2.216	1.875
.242	4.12	.0394	1.71	.312	.391	.798	.236	.091	.268	.358	1.148	.350	.259	1.131	3.636	1.513
.257	3.99	.0650	1.46	.290	.471	.616	.254	.109	.215	.324	1.116	1.043	.105	.713	2.464	1.315
.250	4.41	.0352	1.68	.291	.410	.710	.249	.074	.269	.343	1.178	.338	.220	.94	3.220	1.508
.263	4.39	.0366	1.55	.267	.407	.655	.268	.074	.292	.366	1.37	.279	.264	.214	4.558	1.398
.345	12.00	.0503	5.03	.308	.385	.798	.266	.066	.269	.335	1.090	-	-	-	-	4.303
.351	11.50	.0537	5.37	.354	.402	.881	.275	.067	.214	.281	.795	-	-	-	-	4.580
.248	8.49	.0267	2.67	.241	.461	.522	.377	.036	.271	.307	1.274	.179	.200	.950	3.952	2.360
.264	5.36	.0205	2.05	.298	.396	.752	.314	.031	.276	.307	1.031	.151	.200	.922	3.098	1.893
.266	5.64	.0110	2.20	.299	.400	.746	.330	.033	.271	.304	1.020	.165	.200	.916	3.066	1.973
.250	6.07	.0235	2.35	.308	.422	.730	.335	.032	.244	.276	.897	.174	.189	1.097	3.566	2.165
.266	5.45	.0218	2.18	.307	.381	.807	.302	.027	.281	.308	1.001	.134	.200	.930	3.028	1.985
.266	5.70	.0114	2.26	.305	.379	.805	.320	.028	.284	.312	1.022	.142	.200	.930	3.048	2.068
.354	8.26	.0346	3.46	.340	.446	.763	.339	.047	.193	.241	.707	.224	.213	1.237	3.638	3.150
.263	5.05	.0375	1.88	[illegible]	.370	.759	.276	.032	.314	.346	1.232	.149	.213	.987	3.516	1.720
.251	4.21	.0182	1.46	.267	.450	.593	.344	.055	.255	.310	1.161	.240	.230	1.030	3.864	1.314
-	-	.0556	.31	.333	.525	.610	.249	.159	.109	.268	.805	.955	.166	1.560	7.680	.260
.083	1.02	.0089	.80	.644	.307	2.096	.247	.037	.051	.087	.136	.915	.040	1.000	3.100	.675
.045	0.39	.0156	.23	.482	.390	1.236	.382	.110	.129	.238	.494	1.263	.087	1.340	9.000	.200
.211	2.36	.5159	.34	.109	NA	-	NA	NA	.106	-	-	-	.037	1.848	16.920	.275
.245	9.73	.0637	2.91	.227	NA	-	NA	NA	.156	-	-	-	.011	.444	1.958	2.385
.206	5.22	.2058	.71	.103	.733	.141	.440	.103	.146	.249	2.409	4.312	.024	1.198	11.594	.582

Table 6 Ship Efficiency Parameter Data

VEHICLE	IDENTIFICATION	YEAR ENTER SERVICE	L/D	$\eta_{OVERALL}$	$\eta_{OVERALL} \times L/D$	$\frac{N.Mi}{lb}$ / $\frac{N.Mi.}{lb}$	$P/L \times \frac{N.Mi}{lb}$ / $\frac{ST\text{-}N.Mi}{lb}$	$\frac{P/L}{GW}$	$\frac{OWE}{GW}$	$\frac{P}{OW}$
Surface Dry Cargo Ship	C3-S-A2	1942	290	.184	53.3	3.116×10^{-3}	38.17	.621	.347	1.7
Surface Dry Cargo Ship	C1A	1942	337	.181	60.8	5.687×10^{-3}	43.25	.613	.359	1.7
Surface Dry Cargo Ship	C2-S-AJ1	1943	341	.132	62.1	4.303×10^{-3}	46.44	.645	.327	1.9
Surface Dry Cargo Ship	C1-M-AV1	1944	456	.209	95.1	11.905×10^{-3}	75.11	.683	.300	2.2
Surface Dry Cargo Ship	VC2-S-AP3	1944	256	.206	52.7	3.579×10^{-3}	38.56	.632	.335	1.8
Surface Dry Cargo Ship	C4-S-1a	1952	231	.198	45.7	2.238×10^{-3}	29.97	.567	.395	1.4
Surface Dry Cargo Ship	C3-ST-14a	1958	293	.162	47.5	2.677×10^{-3}	26.35	.481	.483	.9
Surface Dry Cargo Ship	C4-S-57a	1963	228	.209	47.7	2.328×10^{-3}	31.11	.567	.397	1.4
Surface Dry Cargo Ship	C4-ST-67a	1964	247	.173	42.7	2.018×10^{-3}	21.17	.432	.528	.8
Surface Tanker	T2-SE-A1	1942	470	.171	80.3	3.808×10^{-3}	66.61	.718	.260	2.7
Surface Tanker	Med. Tanker	1955	440	.190	83.6	1.737×10^{-3}	72.50	.750	.229	3.2
Surface Tanker	S.S. Manhattan	1962	640	.182	116.7	$.875 \times 10^{-3}$	101.02	.752	.233	3.2
Surface Dry Cargo Ship	742-320S	1975	230	.199	45.7	1.962×10^{-3}	28.91	.548	.414	1.3
Surface Dry Cargo Ship	742-321S	1985	175	.201	35.1	$.804 \times 10^{-3}$	18.62	.459	.492	.9
Surface Dry Cargo Ship	742-320S NUC	1975	230	---	----	----	----	.595	.405	1.4
Surface Dry Cargo Ship	742-321S NUC	1985	175	---	----	----	----	.521	.479	1.0
Hydrofoil Dry Cargo	742-322S	1970	18.5	.168	3.1	3.018×10^{-3}	1.432	.400	.461	.8
Submarine Tanker	TANKER A	1980	292	---	----	----	----	.479	.522	.9
Submarine Tanker	TANKER B	1980	144	---	----	----	----	.395	.606	.6
Submarine Tanker	TANKER C	1980	NA	---	----	----	----	.622	.378	1.6

$\frac{P/L}{OWE}$	$\frac{W_{STRU}}{GW}$	$\frac{W_{PP}}{GW}$	$\frac{W_{F_U}}{GW}$	$\frac{W_{PP} + W_{F_U}}{GW}$	$\frac{W_{PP} + W_{F_U}}{P/L}$	$\frac{W_{PP}}{P}$ $\frac{lb}{SHP_N}$	$\frac{P}{GW}$ $\frac{SHP_N}{lb}$	$\frac{P}{GW \times V_{CRU}}$ $\frac{SHP_N}{ST - KNOT}$	$\frac{P}{P/L \times V_{CRU}}$ $\frac{SHP_N}{ST - KNOT}$	$\frac{P/L \times V_{CRU}}{WORK}$ EQUIV. INPUT
1.192	.199	.038	3.25×10^{-2}	7.06×10^{-2}	.114	176.5	$.215 \times 10^{-3}$	2.613×10^{-2}	4.205×10^{-2}	33.00
1.106	.199	.042	2.83×10^{-2}	7.07×10^{-2}	.116	263.0	$.161 \times 10^{-3}$	2.300×10^{-2}	3.757×10^{-2}	37.30
1.970	.184	.036	2.78×10^{-2}	6.32×10^{-2}	.098	197.9	$.179 \times 10^{-3}$	2.315×10^{-2}	3.586×10^{-2}	40.00
2.269	.166	.027	1.82×10^{-2}	4.48×10^{-2}	.066	290.0	$.092 \times 10^{-3}$	1.750×10^{-2}	2.566×10^{-2}	64.90
1.889	.187	.039	3.28×10^{-2}	7.16×10^{-2}	.113	155.3	$.250 \times 10^{-3}$	3.023×10^{-2}	4.782×10^{-2}	33.25
1.434	.215	.048	3.78×10^{-2}	8.54×10^{-2}	.151	128.5	$.370 \times 10^{-3}$	3.650×10^{-2}	6.437×10^{-2}	25.90
.995	NA	NA	3.65×10^{-2}	NA	NA	NA	$.274 \times 10^{-3}$	3.042×10^{-2}	6.331×10^{-2}	22.73
1.428	.208	.046	3.64×10^{-2}	8.20×10^{-2}	.145	130.2	$.350 \times 10^{-3}$	3.420×10^{-2}	6.023×10^{-2}	27.05
.818	NA	NA	4.08×10^{-2}	NA	NA	NA	$.360 \times 10^{-3}$	3.600×10^{-2}	8.340×10^{-2}	18.38
2.758	.175	.021	2.16×10^{-2}	4.27×10^{-2}	.060	171.9	$.123 \times 10^{-3}$	1.700×10^{-2}	2.366×10^{-2}	57.70
3.279	.169	.021	2.07×10^{-2}	4.13×10^{-2}	.055	114.2	$.180 \times 10^{-3}$	1.997×10^{-2}	2.662×10^{-2}	62.70
3.227	NA	.015	1.49×10^{-2}	2.98×10^{-2}	.040	117.2	$.127 \times 10^{-3}$	1.431×10^{-2}	1.903×10^{-2}	87.80
1.325	.232	.058	3.79×10^{-2}	9.54×10^{-2}	.174	129.0	$.446 \times 10^{-3}$	3.800×10^{-2}	6.930×10^{-2}	25.00
.834	.320	.071	4.93×10^{-2}	12.04×10^{-2}	.262	108.6	$.654 \times 10^{-3}$	5.240×10^{-2}	11.406×10^{-2}	16.12
1.471	.232	.058	------			128.8	$.446 \times 10^{-3}$	3.800×10^{-2}	6.382×10^{-2}	---
1.886	.320	.071	------			108.6	$.654 \times 10^{-3}$	5.240×10^{-2}	10.063×10^{-2}	---
.868	.279	.100	13.96×10^{-2}	23.96×10^{-2}	.599	9.8	10.20×10^{-3}	51.00×10^{-2}	127.50×10^{-2}	1.24
.917	NA	NA	------	NA	NA	NA	$.293 \times 10^{-3}$	2.930×10^{-2}	6.116×10^{-2}	---
.652	NA	NA	------	NA	NA	NA	$.960 \times 10^{-3}$	5.134×10^{-2}	13.011×10^{-2}	---
1.648	.137	.093	------			252.0	$.371 \times 10^{-3}$	3.367×10^{-2}	5.411×10^{-2}	---

2

It will be noted that several of the parameters measure the same kind of efficiency in different terms. Recognizing that not all data is available for all vehicles, the complete group is presented for the sake of making easier future comparison studies.

The P/L-Range curve for each study vehicle is shown in Section 3.2.6. Because the design range is different for nearly all the vehicles, the parameters involving W_{F_U} must be interpreted with care. The fuel fraction is an effective measure of propulsion efficiency between vehicles only when defined at the same range and, particularly for aircraft, when weight and drag are consistent.

The design range, i.e., break point in the P/L-R curve, is taken as the most reasonable point to define the study aircraft's range dependent characteristics. However, there is a certain inconsistency which is impossible to avoid in making these comparisons between aircraft designed for different missions. The two significant items affecting these fractions are:

(1) The amount of growth left in the structure may be different between aircraft. This is reflected in the shape of the P/L-R curve (Fig. 1). It is particularly apparent when comparing the final model in a series with the first release aircraft. Recognizing this fact is important to the interpretation of weight fraction data.

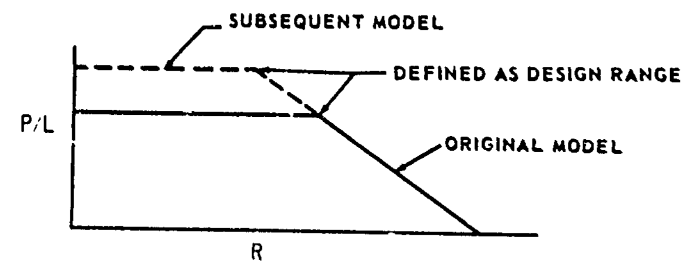


Fig. 1 Payload Growth for Typical Aircraft P/L~R Curve

Fig. 2 shows the relationship, in time, between the aircraft of this study with the first aircraft of its series. Several additional aircraft, not a part of this study, are shown for their interest.

(2) The takeoff field length capability of the respective aircraft may be

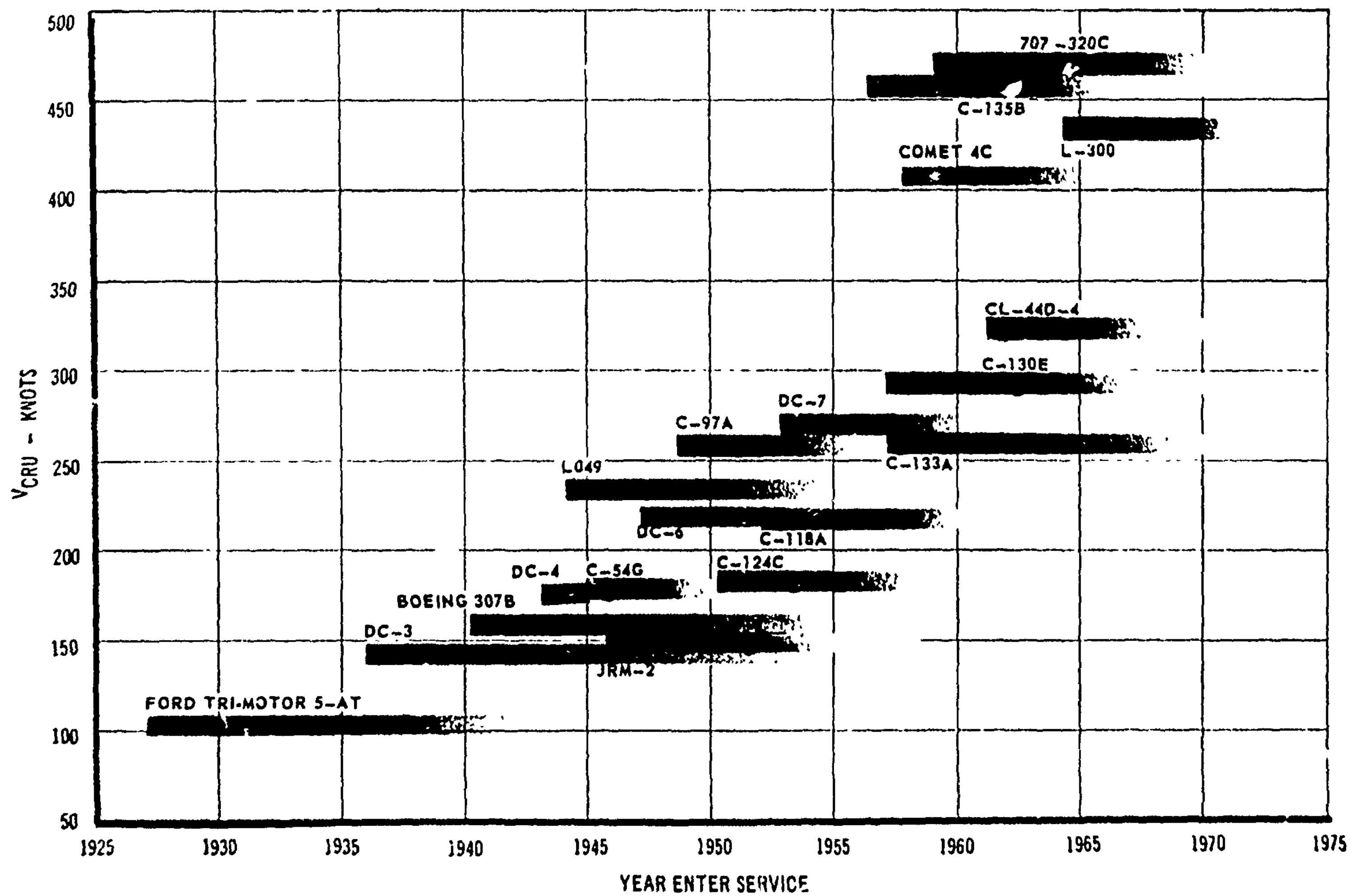


Fig. 2 Airplane Model Growth Characteristics

greatly different. This implies a difference in wing loading and power or thrust loading. These items have an effect on fuel consumption and hence on the weight fractions. Understanding of this point is also necessary.

Range performance calculations for marine vehicles are commonly given a wider tolerance than those for aircraft. This is typified by the several power ratings given marine engines which vary according to the RPM chosen. In this study, marine power plants are defined in terms of the installed normal shaft horsepower. This rating is understood to contain a 25 percent power margin over the shaft horsepower required to drive the vessel at its design speed with zero wind, clean bottom, and calm sea. The power margin is to permit the maintenance of sustained sea speed under typical operating conditions with moderate fouling of the hull. Fuel consumption data available for cargo ship operation are quoted in barrels/day. This somewhat coarse measure is consistent with the average power and speed figures commonly used.

4000 N. Mi. was chosen as the distance for defining all range dependent ship parameters. This distance is close to the voyage length for many trade routes. A more rigorous definition of this range would involve consideration of specific missions and is beyond the scope of this study. Inspection of the Payload-Range curves of Section 3.2.6 shows that the slope is much flatter for ships than for aircraft. This means that the rate of change of fuel fraction with range is smaller for ships than for aircraft and substantiates the reasonableness of a single range for all ships.

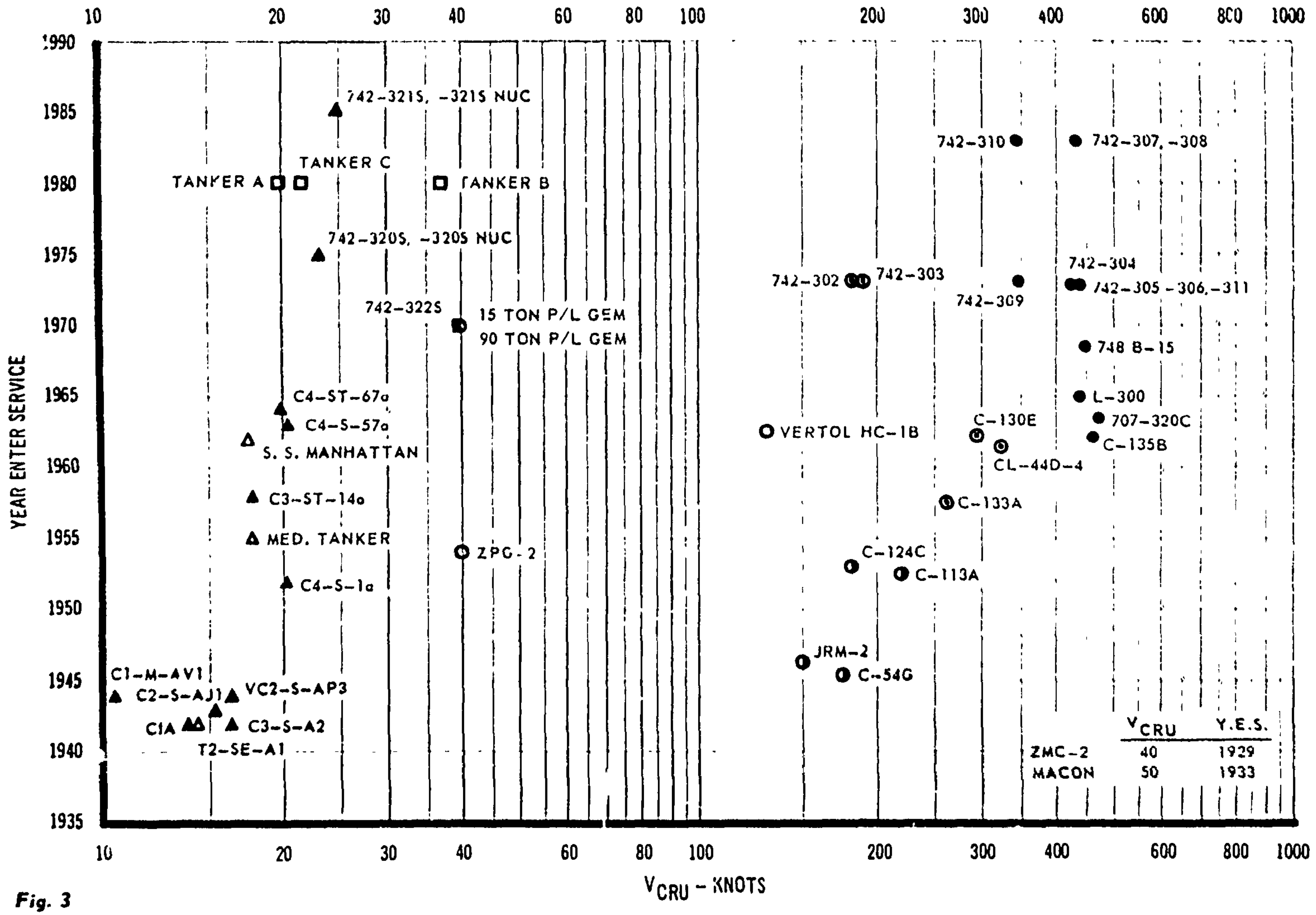
The hydrofoil craft range dependent parameters are defined at 1000 N. Mi. because of its more limited capability.

3.2 PLOTTED DATA

The data are arranged by Groups I through V as discussed in Section 3.1. Each group is organized in the order shown for the parameters. The following symbols are used on the plots:

- ◐ Reciprocating Engine Airplane
- ⊕ Turboprop Airplane
- ● Turbofan or Turbojet Airplane
- ○ Non-airplane Aircraft
- ▲ Dry Cargo Surface Ship
- △ Tanker Surface Ship
- □ Tanker Submarine
- ■ Hydrofoil Ship

3.2.1 DATA PLOTTED vs V_{cru}



YEAR ENTER SERVICE
V_CRU - KNOTS
742-321S, -321S NUC
TANKER C
TANKER A
TANKER B
742-320S, -320S NUC
742-322S
15 TON P/L GEM
90 TON P/L GEM
C4-ST-67a
C4-S-57a
S. S. MANHATTAN
C3-ST-14a
MED. TANKER
ZPG-2
C4-S-1a
C1-M-AV1
C2-S-AJ1
VC2-S-AP3
C1A
C3-S-A2
T2-SE-A1
742-310
742-307, -308
742-302
742-303
742-304
742-305 -306, -311
742-309
748 B-15
L-300
707-320C
C-135B
VERTOL HC-1B
C-130E
CL-44D-4
C-133A
C-124C
C-113A
JRM-2
C-54G
V_CRU
Y.E.S.
ZMC-2
40
1929
MACON
50
1933

Fig. 3

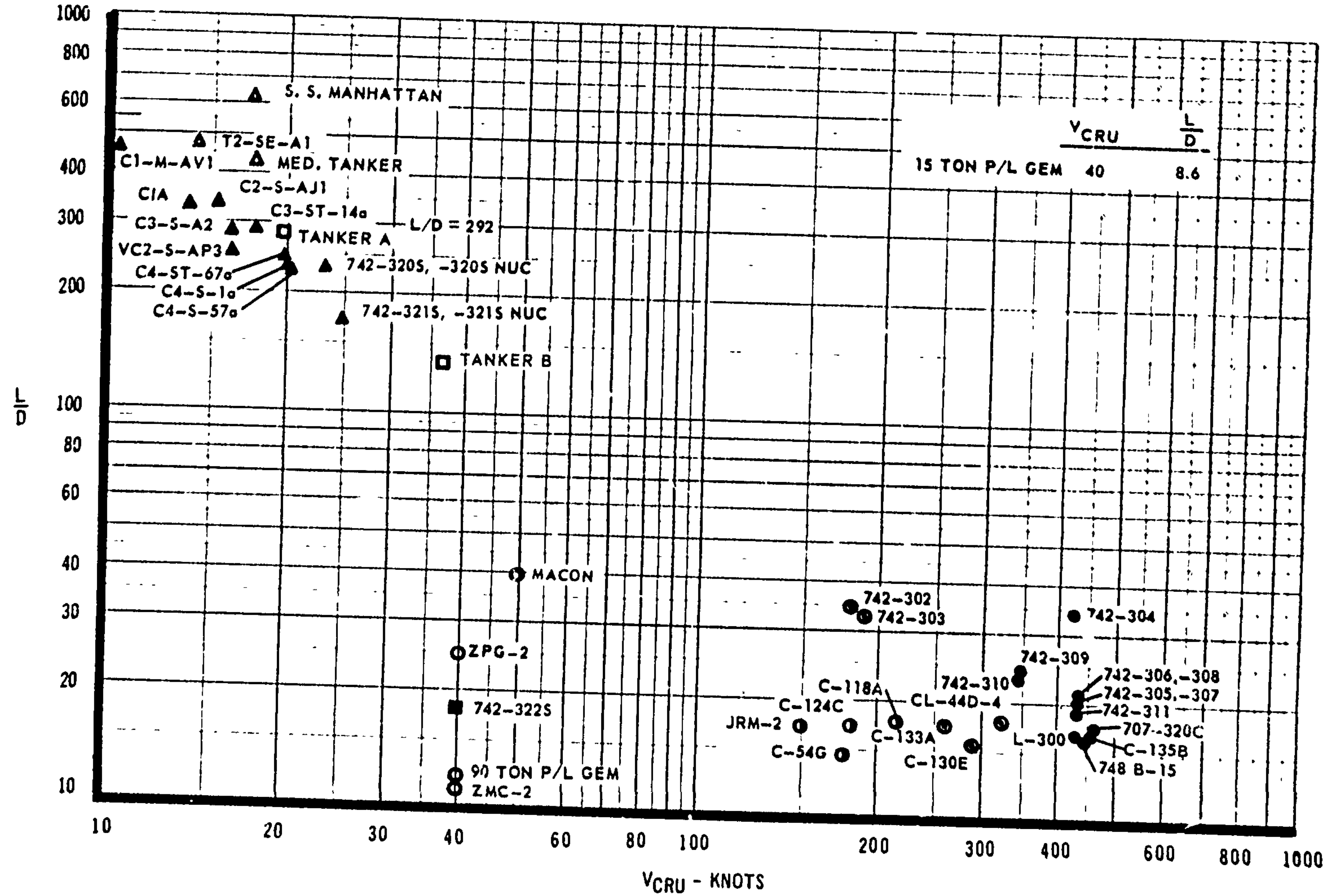
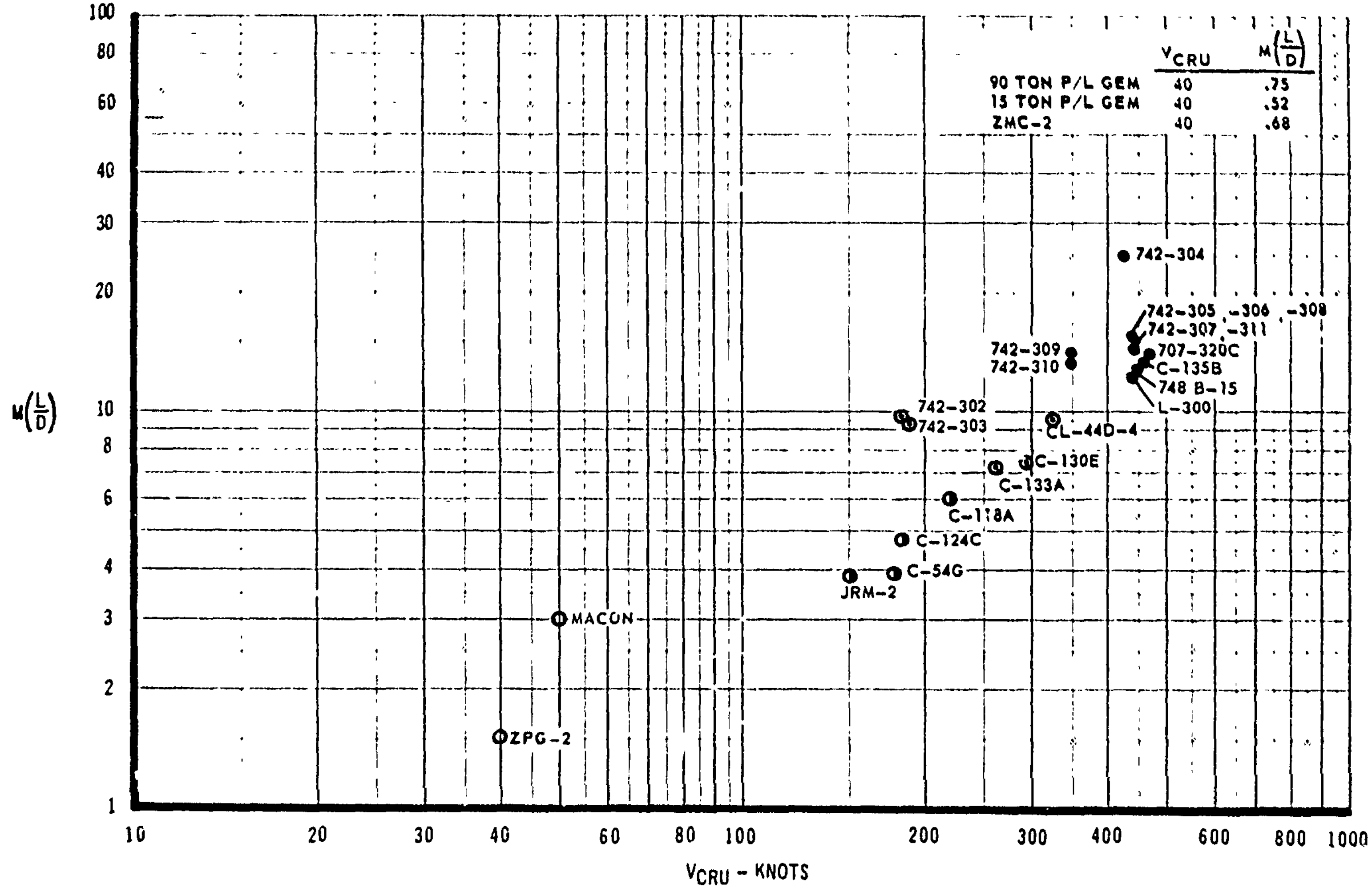
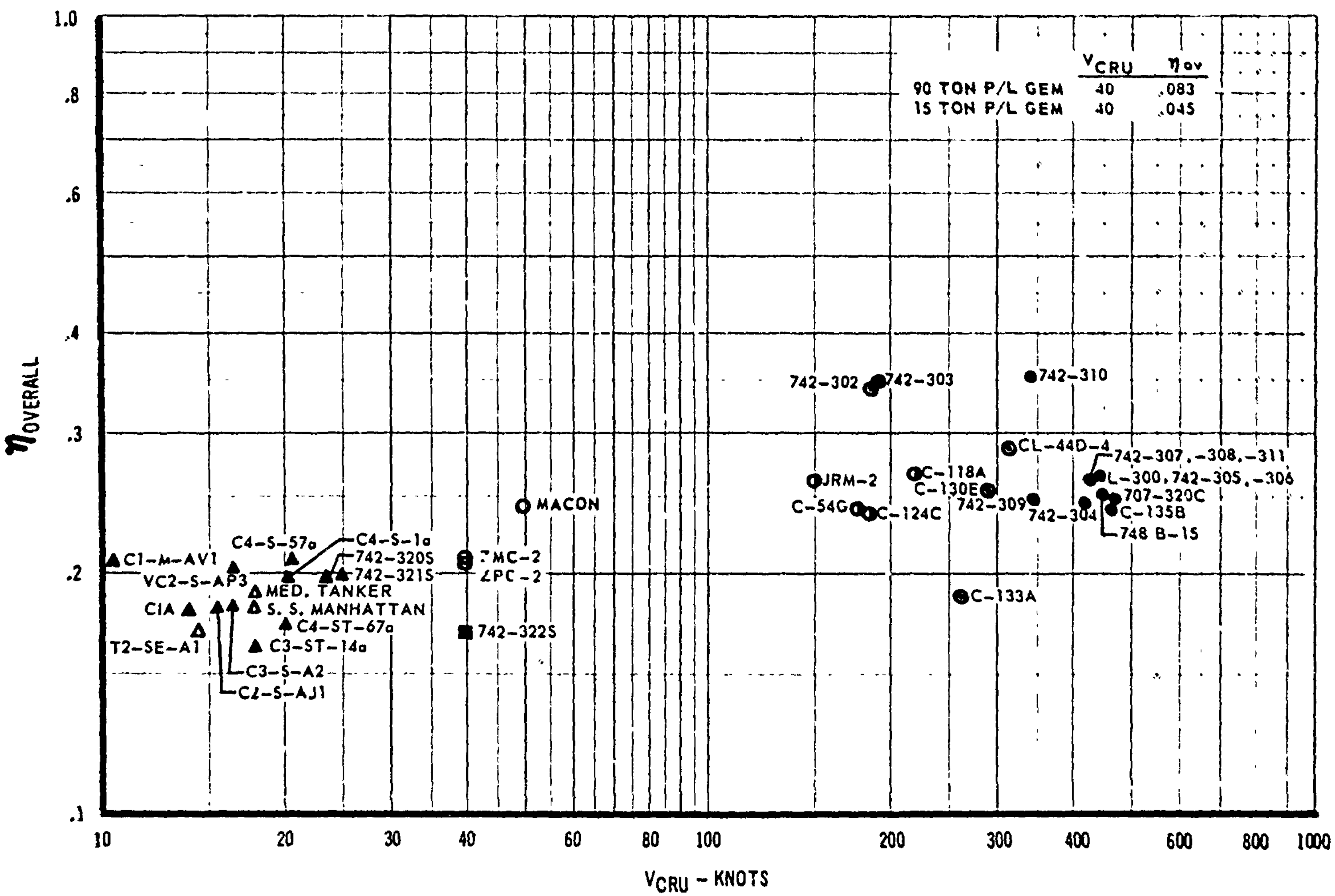

S. S. MANHATTAN
T2-SE-A1
C1-M-AV1
MED. TANKER
C2-S-AJ1
CIA
C3-ST-14a
C3-S-A2
TANKER A
L/D = 292
VC2-S-AP3
C4-ST-67a
C4-S-1a
C4-S-57a
742-320S, -320S NUC
742-321S, -321S NUC
TANKER B
MACON
ZPG-2
742-322S
90 TON P/L GEM
ZMC-2
742-302
742-303
742-304
742-309
742-310
742-306, -308
742-305, -307
742-311
707-320C
C-135B
748 B-15
L-300
C-118A
C-124C
CL-44D-4
JRM-2
C-133A
C-54G
C-130E
V_{CRU}
$\frac{L}{D}$
15 TON P/L GEM 40 8.6
V_{CRU} - KNOTS

Fig. 4



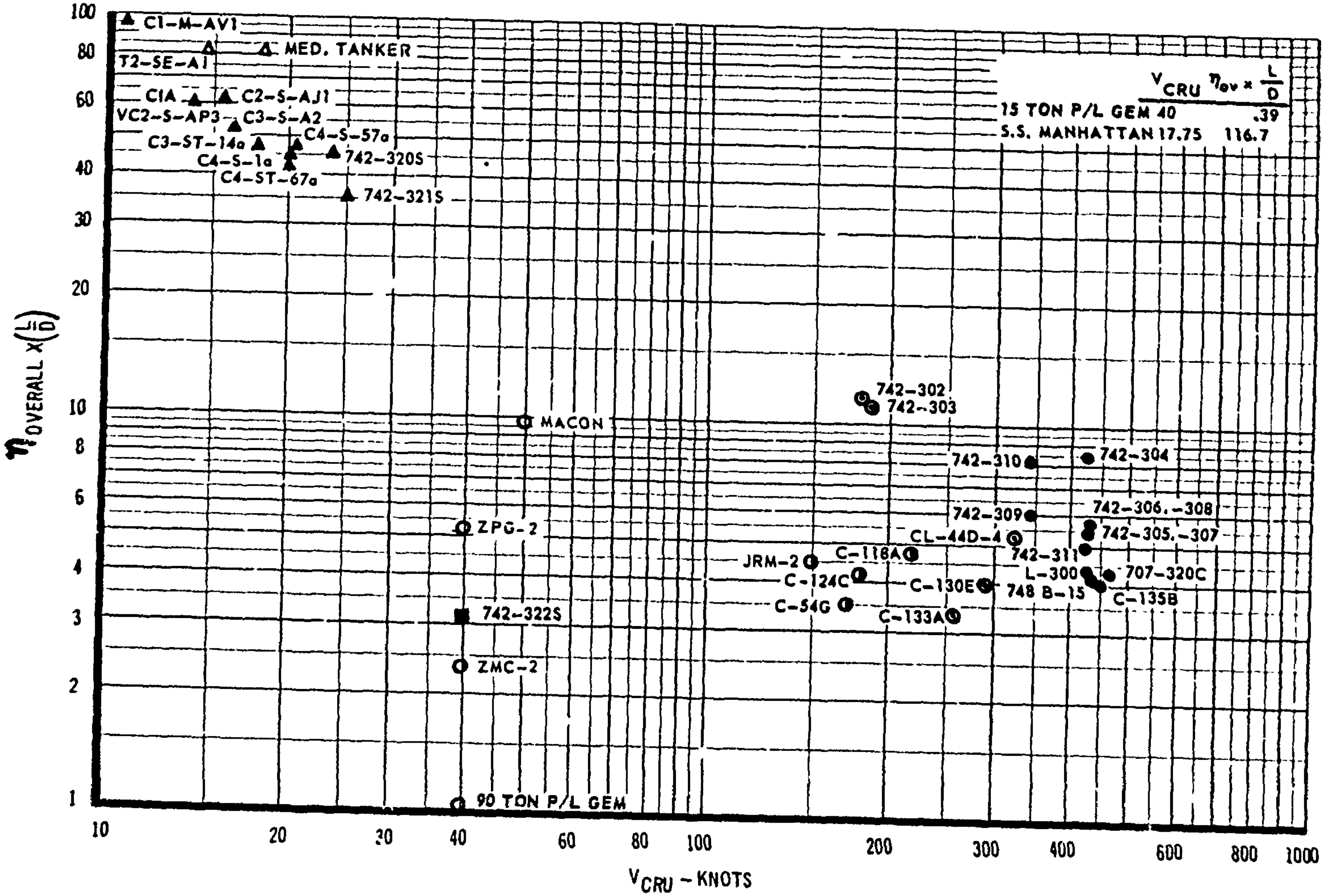
100
80
60
40
30
20
10
8
6
4
3
2
1
M(L/D)
10
20
30
40
60
80
100
200
300
400
600
800
1000
VCRU - KNOTS
VCRU
M(L/D)
90 TON P/L GEM 40 .75
15 TON P/L GEM 40 .52
ZMC-2 40 .68
742-304
742-305, -306, -308
742-307, -311
707-320C
C-135B
748 B-15
L-300
742-309
742-310
742-302
742-303
CL-44D-4
C-130E
C-133A
C-118A
C-124C
C-54G
JRM-2
MACON
ZPG-2

Fig. 5



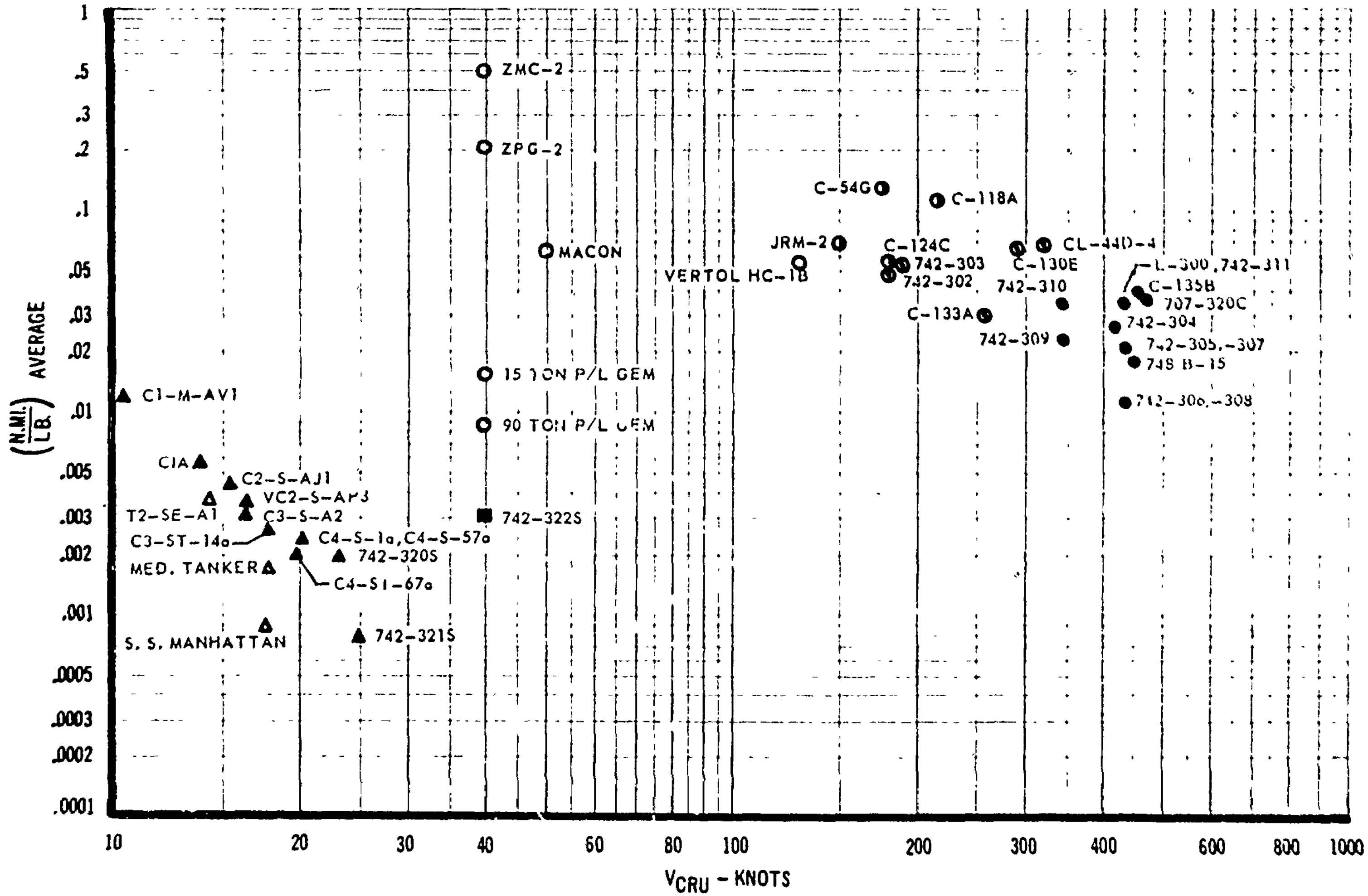
V_{CRU} η_{ov}
90 TON P/L GEM 40 .083
15 TON P/L GEM 40 .045
742-302
742-303
742-310
CL-44D-4
742-307, -308, -311
L-300, 742-305, -306
707-320C
C-135B
748 B-15
742-304
742-309
C-118A
C-130E
JRM-2
C-54G
C-124C
C-133A
MACON
MC-2
PC-2
742-322S
C1-M-AV1
VC2-S-AP3
C4-S-57a
C4-S-1a
742-320S
742-321S
MED. TANKER
S. S. MANHATTAN
C4-ST-67a
C3-ST-14a
C3-S-A2
C2-S-AJ1
CIA
T2-SE-A1
$\eta_{OVERALL}$
V_{CRU} – KNOTS

Fig. 6



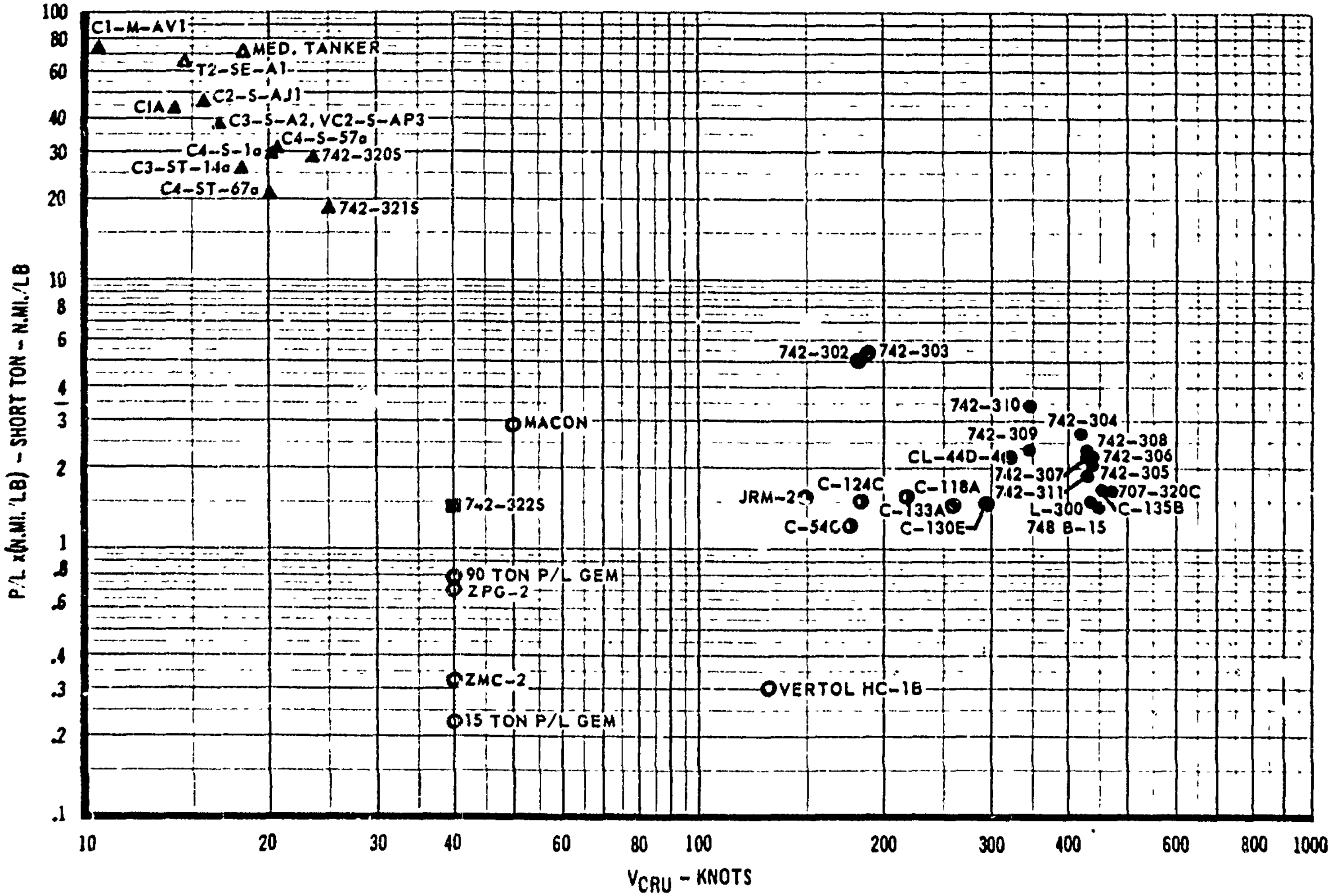
C1-M-AV1
T2-SE-A1
MED. TANKER
C1A
C2-S-AJ1
VC2-S-AP3
C3-S-A2
C4-S-57a
C3-ST-14a
C4-S-1a
742-320S
C4-ST-67a
742-321S
V_{CRU} $\eta_{ov} \times \frac{L}{D}$
15 TON P/L GEM 40 .39
S.S. MANHATTAN 17.75 116.7
742-302
742-303
MACON
742-310
742-304
742-309
742-306, -308
742-305, -307
ZPG-2
CL-44D-4
742-311
JRM-2
C-118A
C-124C
C-130E
L-300
707-320C
748 B-15
C-135B
C-54G
C-133A
742-322S
ZMC-2
90 TON P/L GEM
$\eta_{OVERALL} \times \left(\frac{L}{D}\right)$
V_{CRU} - KNOTS

Fig. 7



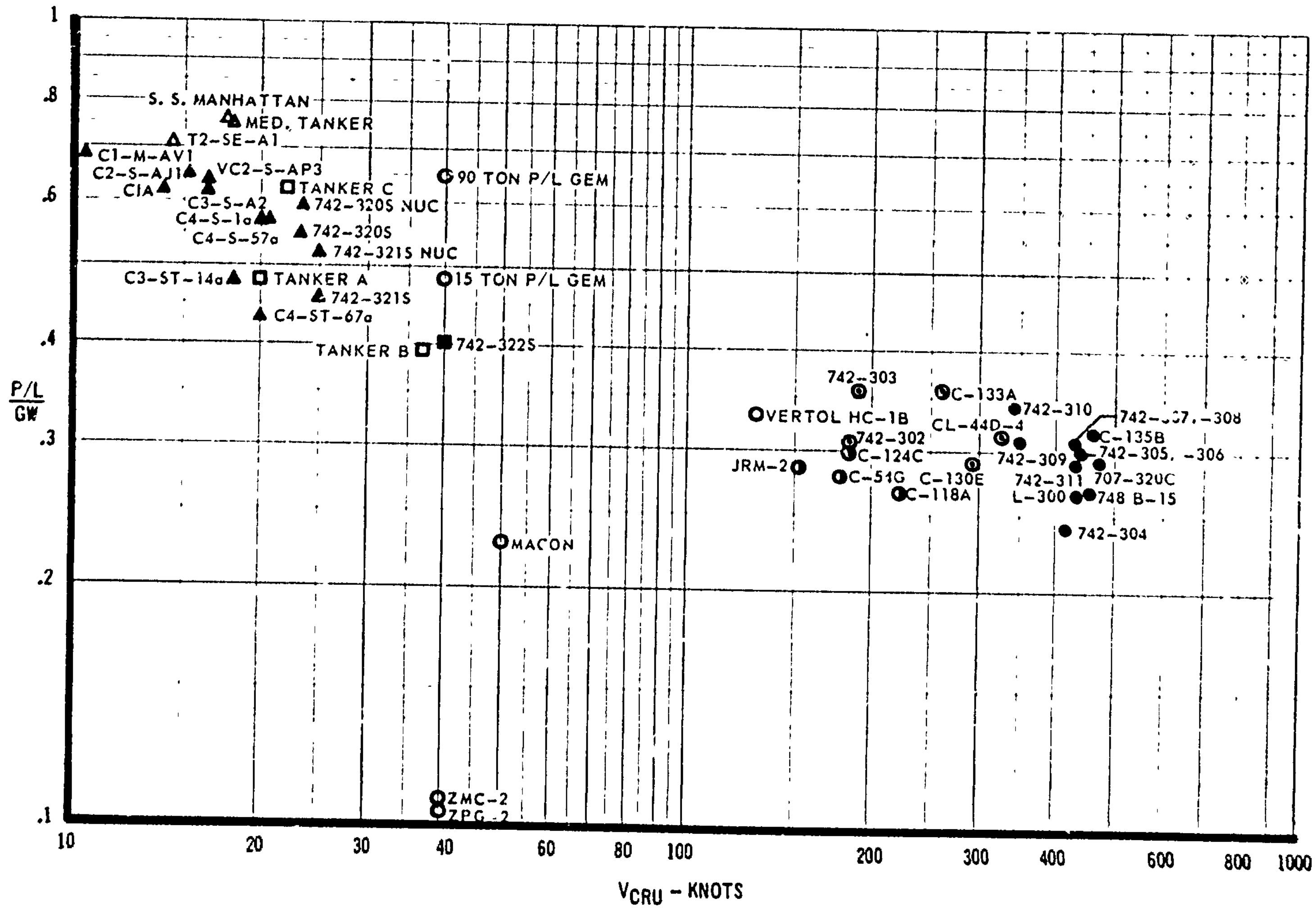
ZMC-2
ZPG-2
MACON
15 TON P/L GEM
90 TON P/L GEM
742-322S
C1-M-AV1
C1A
C2-S-AJ1
VC2-S-AP3
T2-SE-A1
C3-S-A2
C3-ST-14a
C4-S-1a, C4-S-57a
742-320S
MED. TANKER
C4-S1-67a
S. S. MANHATTAN
742-321S
VERTOL HC-1B
JRM-2
C-54G
C-118A
C-124C
742-303
742-302
C-133A
C-130E
CL-44D-4
742-310
742-309
L-300, 742-311
C-135B
707-320C
742-304
742-305, -307
748 B-15
742-306, -308
V_{CRU} - KNOTS
(N.MI./LB.) AVERAGE

Fig. 8



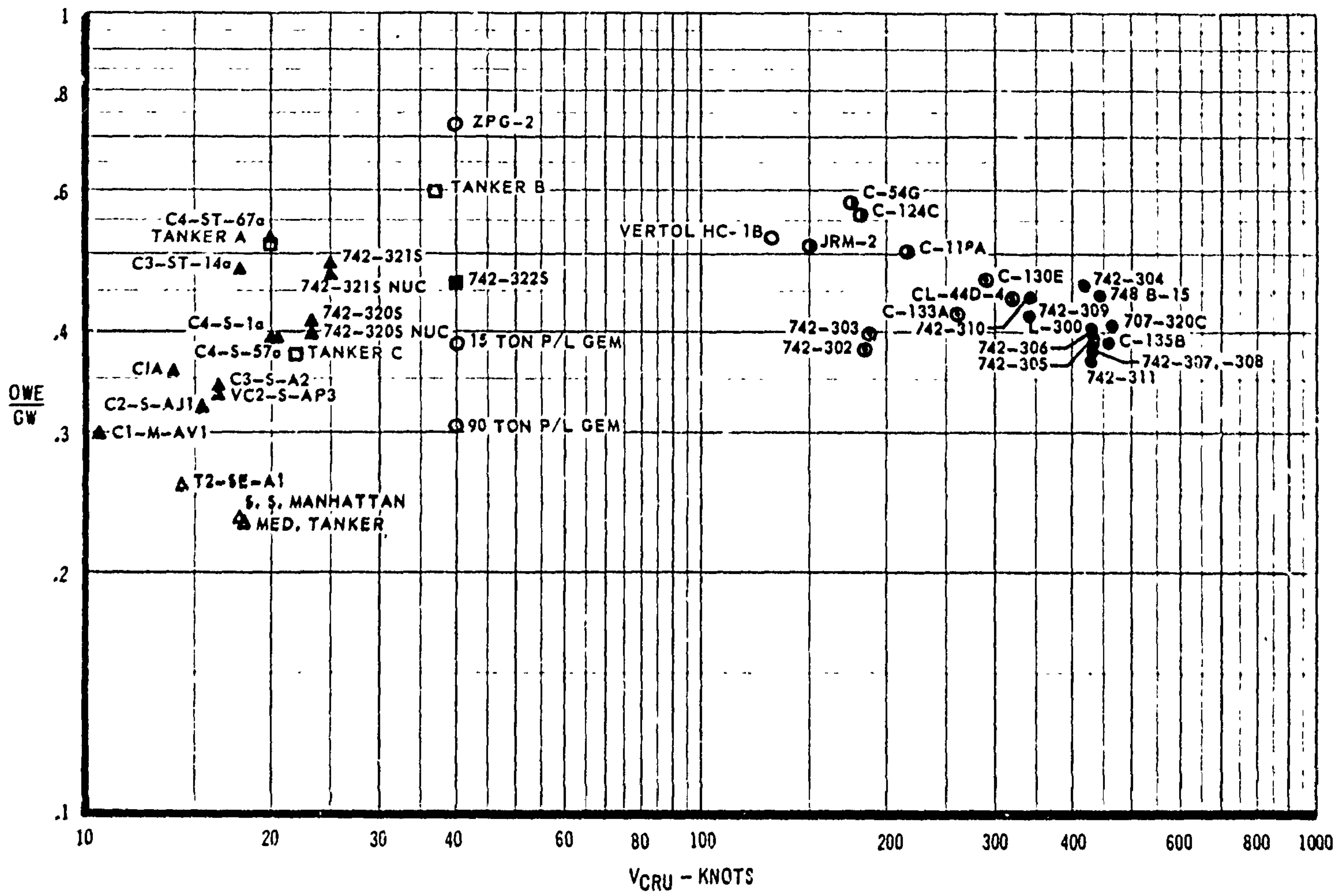
C1-M-AV1
MED. TANKER
T2-SE-A1
C2-S-AJ1
C1A
C3-S-A2, VC2-S-AP3
C4-S-57a
C4-S-1a
742-320S
C3-ST-14a
C4-ST-67a
742-321S
742-302
742-303
742-310
742-304
742-309
742-308
742-306
CL-44D-4
742-307
742-305
742-311
707-320C
C-124C
C-118A
JRM-2
C-133A
L-300
C-135B
C-54C
C-130E
748 B-15
MACON
742-322S
90 TON P/L GEM
ZPG-2
ZMC-2
VERTOL HC-1B
15 TON P/L GEM
P/L x (N.MI./LB) - SHORT TON - N.MI./LB
V_{CRU} - KNOTS

Fig. 9



S. S. MANHATTAN
MED. TANKER
T2-SE-A1
C1-M-AV1
C2-S-AJ1
VC2-S-AP3
CIA
C3-S-A2
C4-S-1a
C4-S-57a
TANKER C
742-320S NUC
742-320S
742-321S NUC
90 TON P/L GEM
C3-ST-14a
TANKER A
742-321S
C4-ST-67a
15 TON P/L GEM
TANKER B
742-322S
MACON
ZMC-2
ZPG-2
742-303
VERTOL HC-1B
742-302
C-124C
JRM-2
C-51G
C-133A
CL-44D-4
C-130E
C-118A
742-310
742-309
742-311
L-300
742-304
C-135B
742-305, -306
707-320C
748 B-15
P/L / GW
VCRU - KNOTS

Fig. 10



ZPG-2
TANKER B
C4-ST-67a
TANKER A
C3-ST-14a
742-321S
742-321S NUC
742-322S
742-320S
742-320S NUC
C4-S-1a
C4-S-57a
TANKER C
15 TON P/L GEM
CIA
C3-S-A2
VC2-S-AP3
C2-S-AJ1
C1-M-AV1
90 TON P/L GEM
T2-SE-A1
S. S. MANHATTAN
MED. TANKER
VERTOL HC-1B
JRM-2
C-54G
C-124C
C-11PA
C-130E
CL-44D-4
C-133A
742-303
742-302
742-310
742-304
748 B-15
742-309
L-300
707-320C
C-135B
742-306
742-305
742-307, -308
742-311
OWE/GW
VCRU - KNOTS

Fig. 11

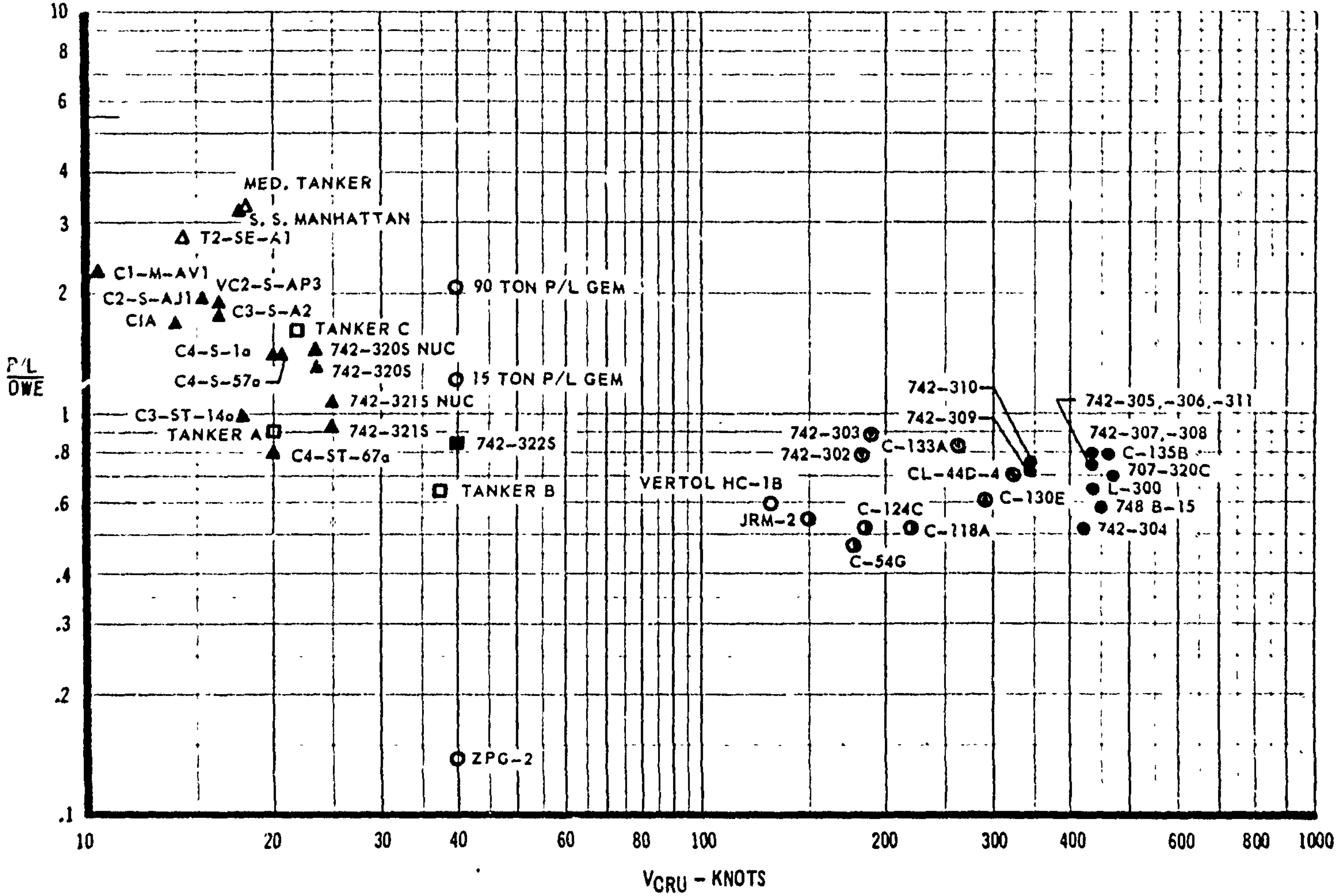
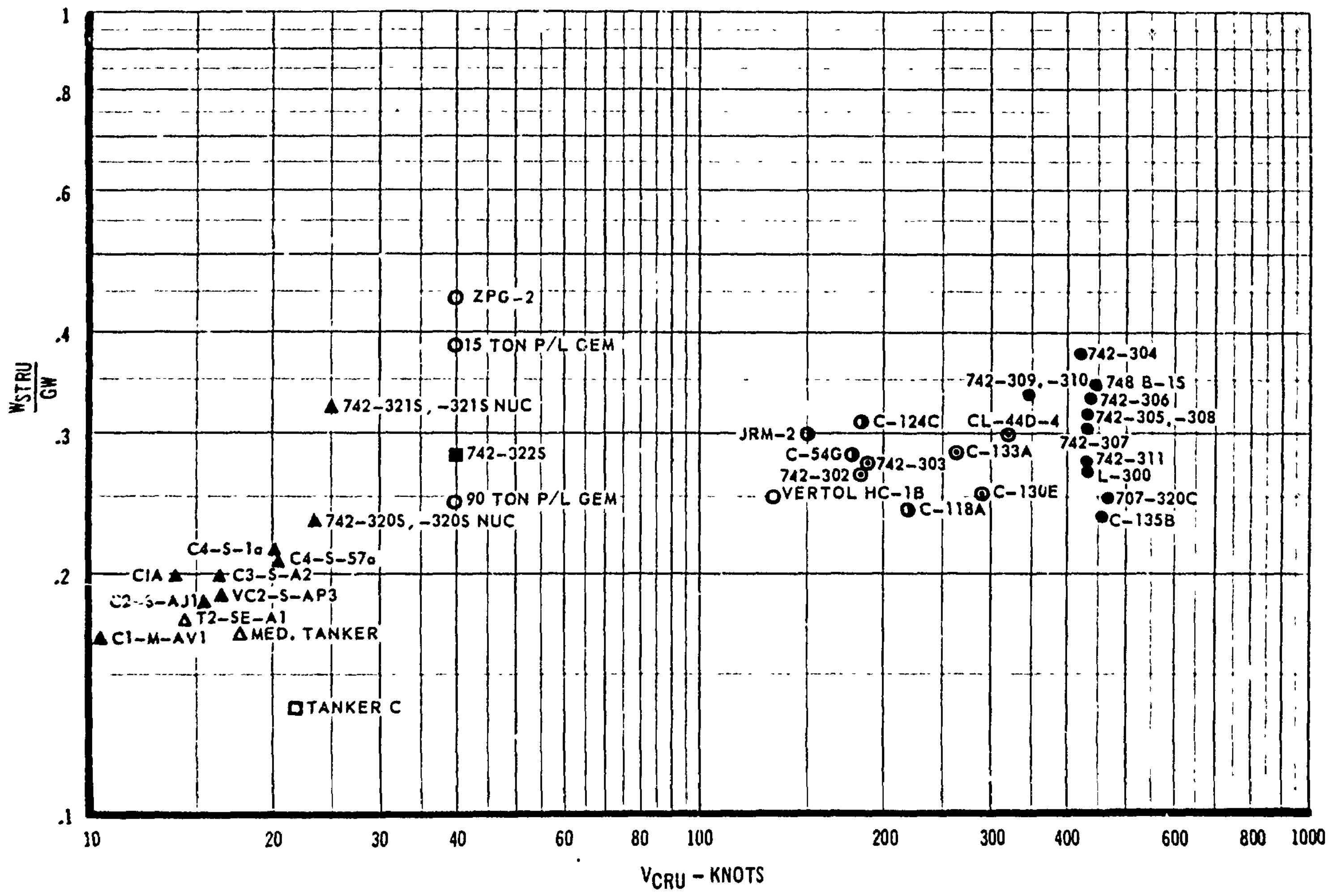
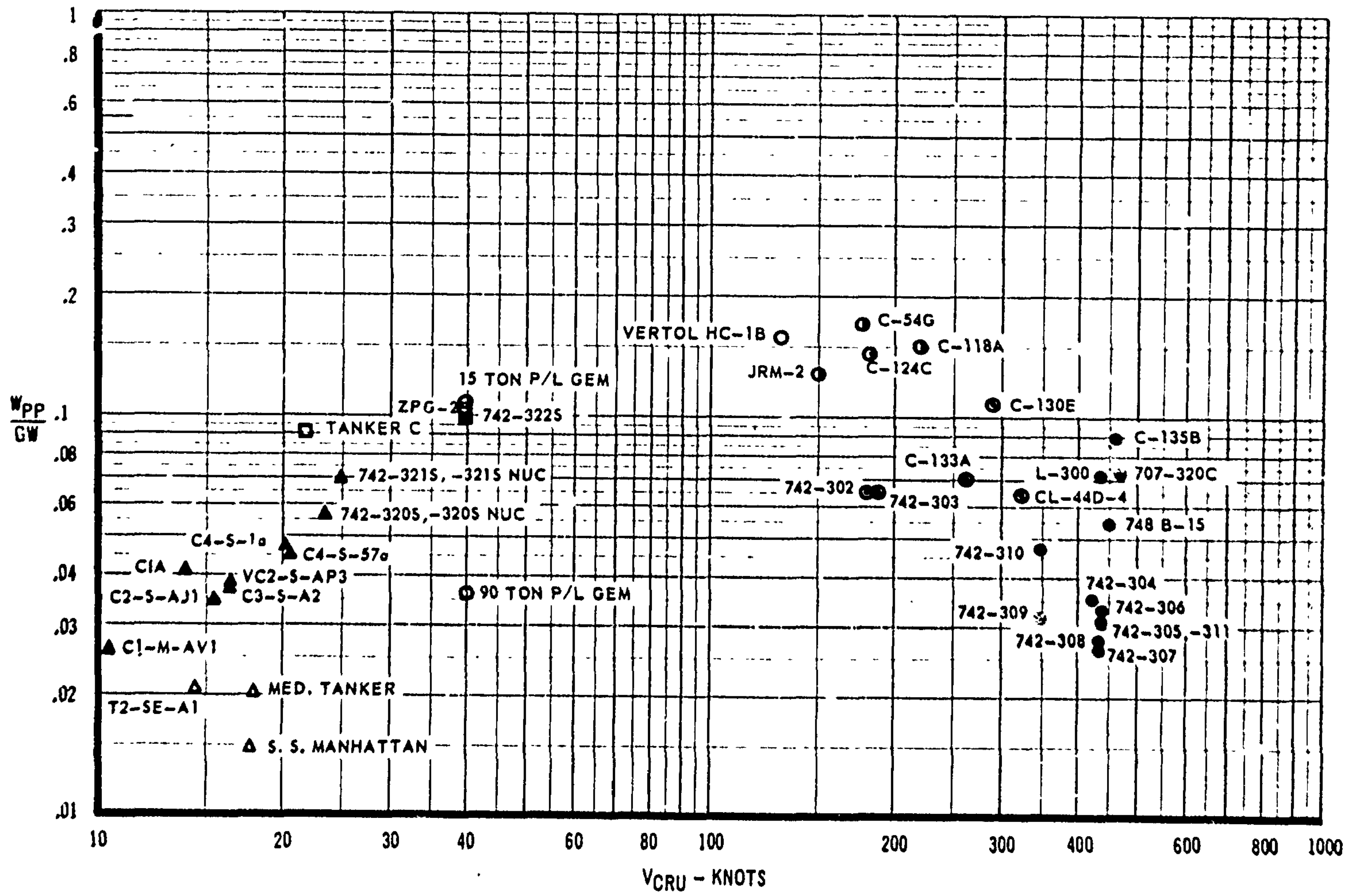

P/L / OWE
10
8
6
4
3
2
1
.8
.6
.4
.3
.2
.1
10
20
30
40
60
80
100
200
300
400
600
800
1000
V_{CRU} - KNOTS
MED. TANKER
S. S. MANHATTAN
T2-SE-A1
C1-M-AV1
VC2-S-AP3
C2-S-AJ1
C3-S-A2
CIA
TANKER C
C4-S-1a
742-320S NUC
742-320S
C4-S-57a
742-321S NUC
C3-ST-14a
742-321S
TANKER A
C4-ST-67a
742-322S
TANKER B
90 TON P/L GEM
15 TON P/L GEM
ZPG-2
VERTOL HC-1B
JRM-2
C-124C
C-54G
C-118A
742-303
742-302
C-133A
CL-44D-4
C-130E
742-310
742-309
742-305,-306,-311
742-307,-308
C-135B
707-320C
L-300
748 B-15
742-304

Fig. 12



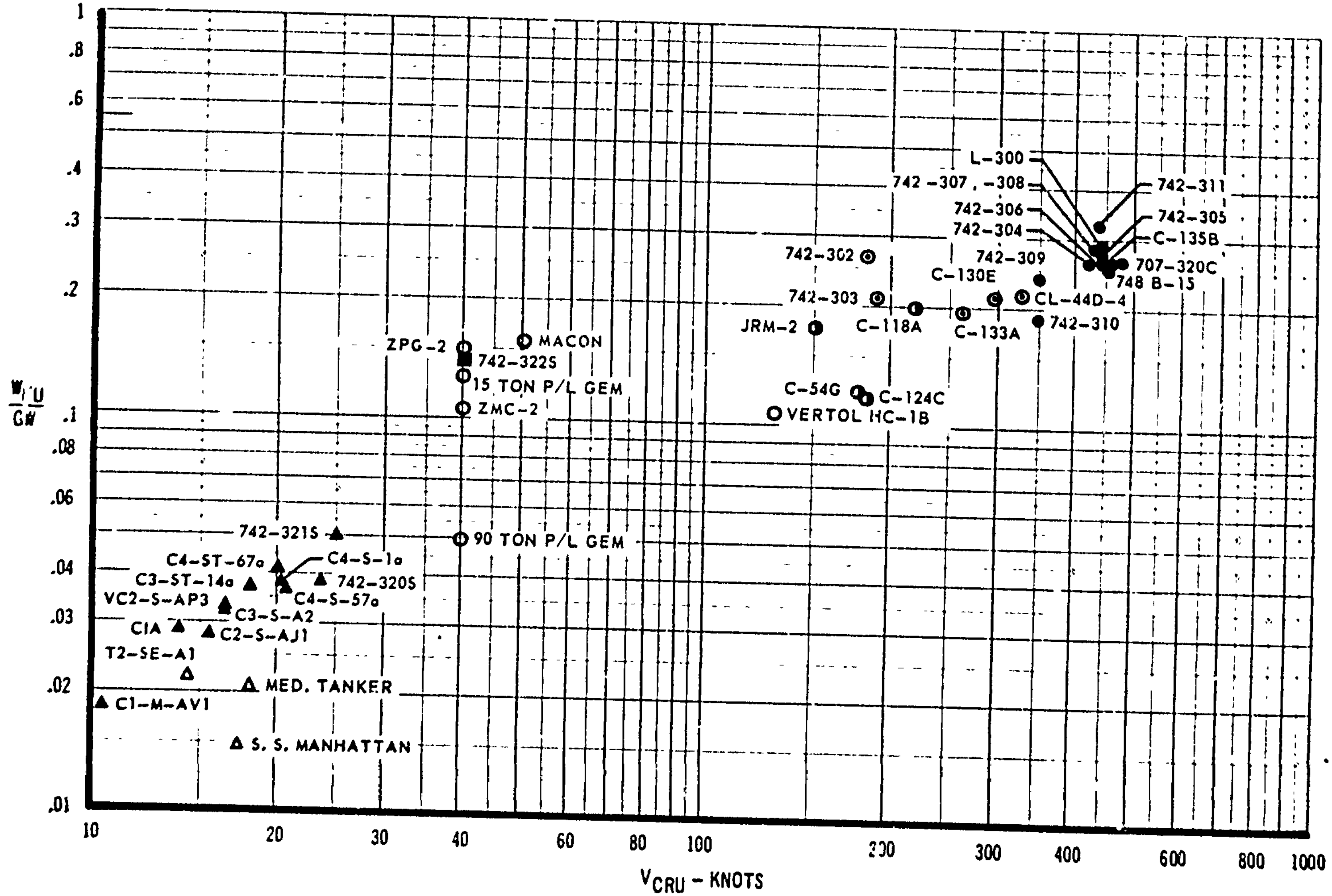
ZPG-2
15 TON P/L GEM
742-321S, -321S NUC
742-322S
90 TON P/L GEM
742-320S, -320S NUC
C4-S-1a
C4-S-57a
CIA
C3-S-A2
VC2-S-AP3
T2-SE-A1
C1-M-AV1
MED. TANKER
TANKER C
742-304
742-309, -310
748 B-1S
742-306
742-305, -308
JRM-2
C-124C
CL-44D-4
742-307
C-54G
742-303
C-133A
742-311
742-302
L-300
VERTOL HC-1B
C-130E
707-320C
C-118A
C-135B
1
.8
.6
.4
.3
.2
.1
10
20
30
40
60
80
100
200
300
400
600
800
1000
$\frac{W_{STRU}}{GW}$
V_{CRU} - KNOTS

Fig. 13



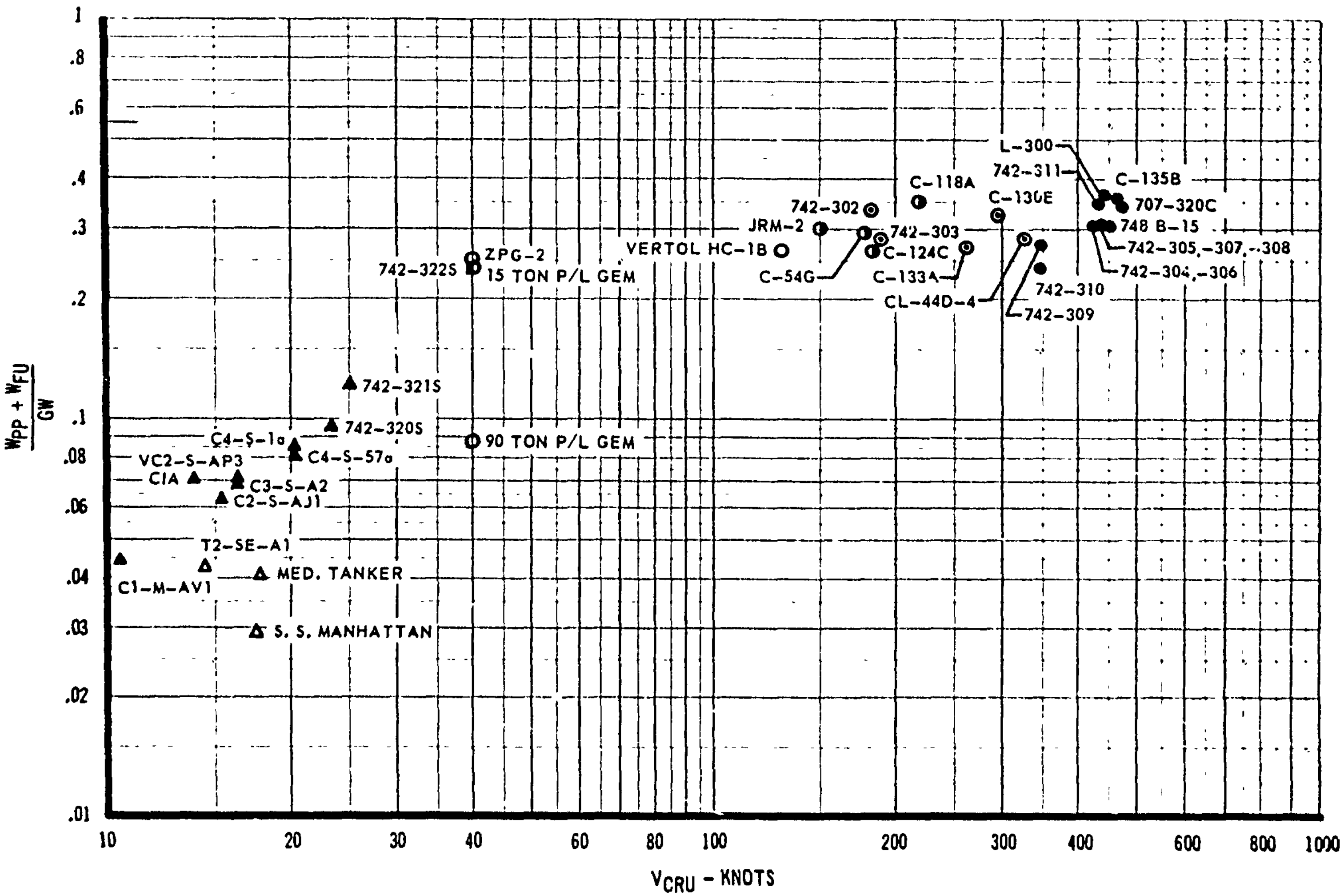
VERTOL HC-1B
C-54G
C-118A
C-124C
JRM-2
15 TON P/L GEM
ZPG-2
742-322S
TANKER C
C-130E
C-135B
C-133A
742-302
742-303
L-300
707-320C
CL-44D-4
748 B-15
742-310
742-304
742-306
742-305, -311
742-307
742-308
742-309
742-321S, -321S NUC
742-320S, -320S NUC
C4-S-1a
C4-S-57a
CIA
VC2-S-AP3
C2-S-AJ1
C3-S-A2
90 TON P/L GEM
C1-M-AV1
T2-SE-A1
MED. TANKER
S. S. MANHATTAN
$\frac{W_{PP}}{GW}$
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
10
20
30
40
60
80
100
200
300
400
600
800
1000
V_{CRU} - KNOTS

Fig. 14



L-300
742-307, -308
742-306
742-304
742-311
742-305
C-135B
707-320C
748 B-15
742-309
742-302
C-130E
742-303
CL-44D-4
JRM-2
C-118A
C-133A
742-310
C-54G
C-124C
VERTOL HC-1B
ZPG-2
MACON
742-322S
15 TON P/L GEM
ZMC-2
742-321S
90 TON P/L GEM
C4-ST-67a
C4-S-1a
C3-ST-14a
742-320S
VC2-S-AP3
C4-S-57a
C3-S-A2
C1A
C2-S-AJ1
T2-SE-A1
MED. TANKER
C1-M-AV1
S. S. MANHATTAN
1
.8
.6
.4
.3
.2
$\frac{W_{PL} U}{GW}$
.1
.08
.06
.04
.03
.02
.01
10
20
30
40
60
80
100
200
300
400
600
800
1000
V_{CRU} - KNOTS

Fig. 15



1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
$\frac{W_{PP} + W_{FU}}{GW}$
10
20
30
40
60
80
100
200
300
400
600
800
1000
V_{CRU} - KNOTS
L-300
742-311
C-135B
707-320C
748 B-15
742-305,-307,-308
742-304,-306
742-310
742-309
C-118A
C-130E
742-302
JRM-2
742-303
C-124C
C-133A
CL-44D-4
C-54G
VERTOL HC-1B
ZPG-2
742-322S
15 TON P/L GEM
742-321S
742-320S
90 TON P/L GEM
C4-S-1a
C4-S-57a
VC2-S-AP3
CIA
C3-S-A2
C2-S-AJ1
T2-SE-A1
MED. TANKER
C1-M-AV1
S. S. MANHATTAN

Fig. 16

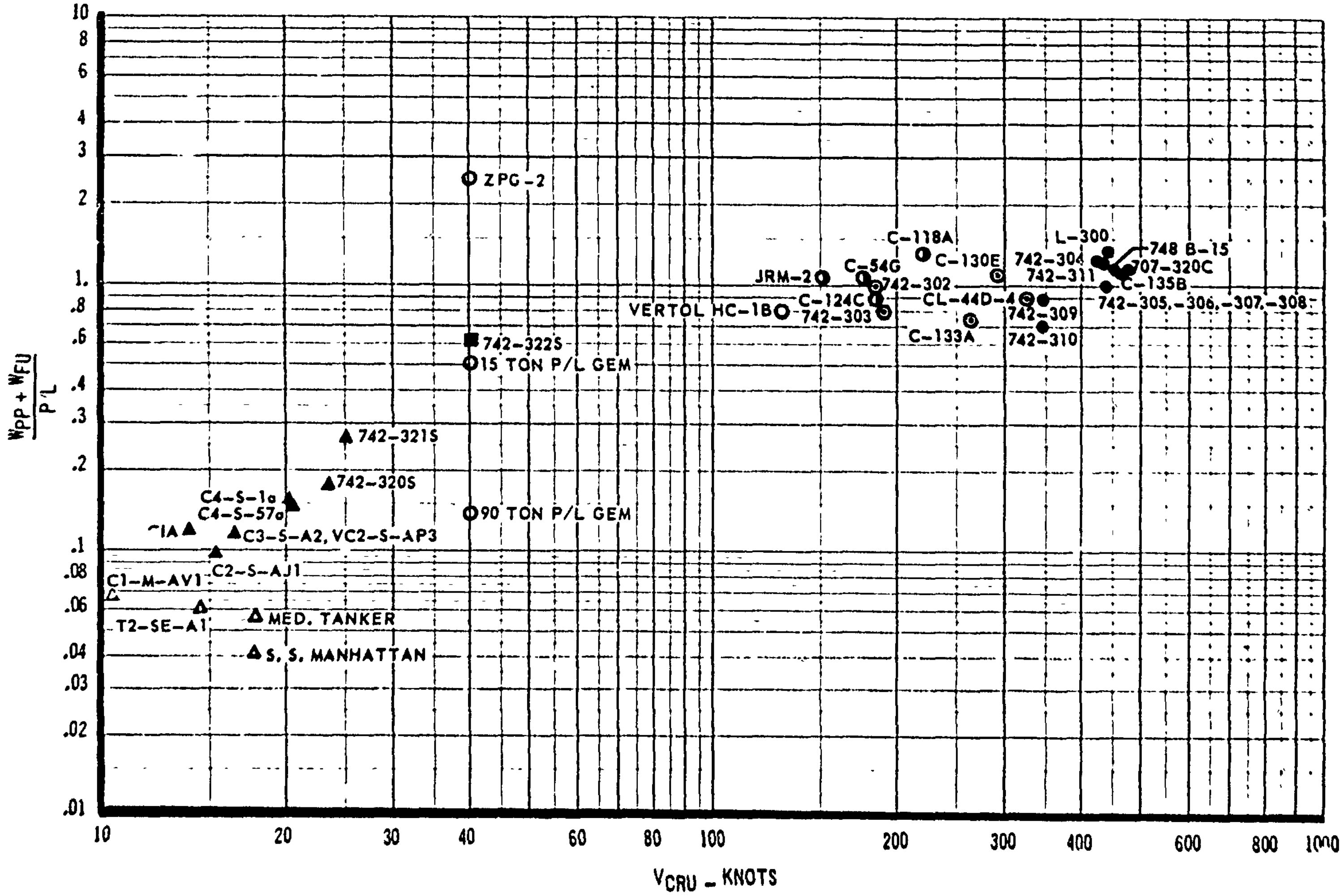

ZPG-2
742-322S
15 TON P/L GEM
90 TON P/L GEM
742-321S
742-320S
C4-S-1a
C4-S-57a
C3-S-A2, VC2-S-AP3
C2-S-AJ1
C1-M-AV1
T2-SE-A1
MED. TANKER
S. S. MANHATTAN
C-118A
C-130E
C-54G
742-302
JRM-2
C-124C
742-303
VERTOL HC-1B
CL-44D-4
742-309
C-133A
742-310
L-300
748 B-15
707-320C
742-304
742-311
C-135B
742-305, -306, -307, -308
$\frac{W_{PP} + W_{FU}}{P/L}$
V_{CRU} – KNOTS

Fig. 17

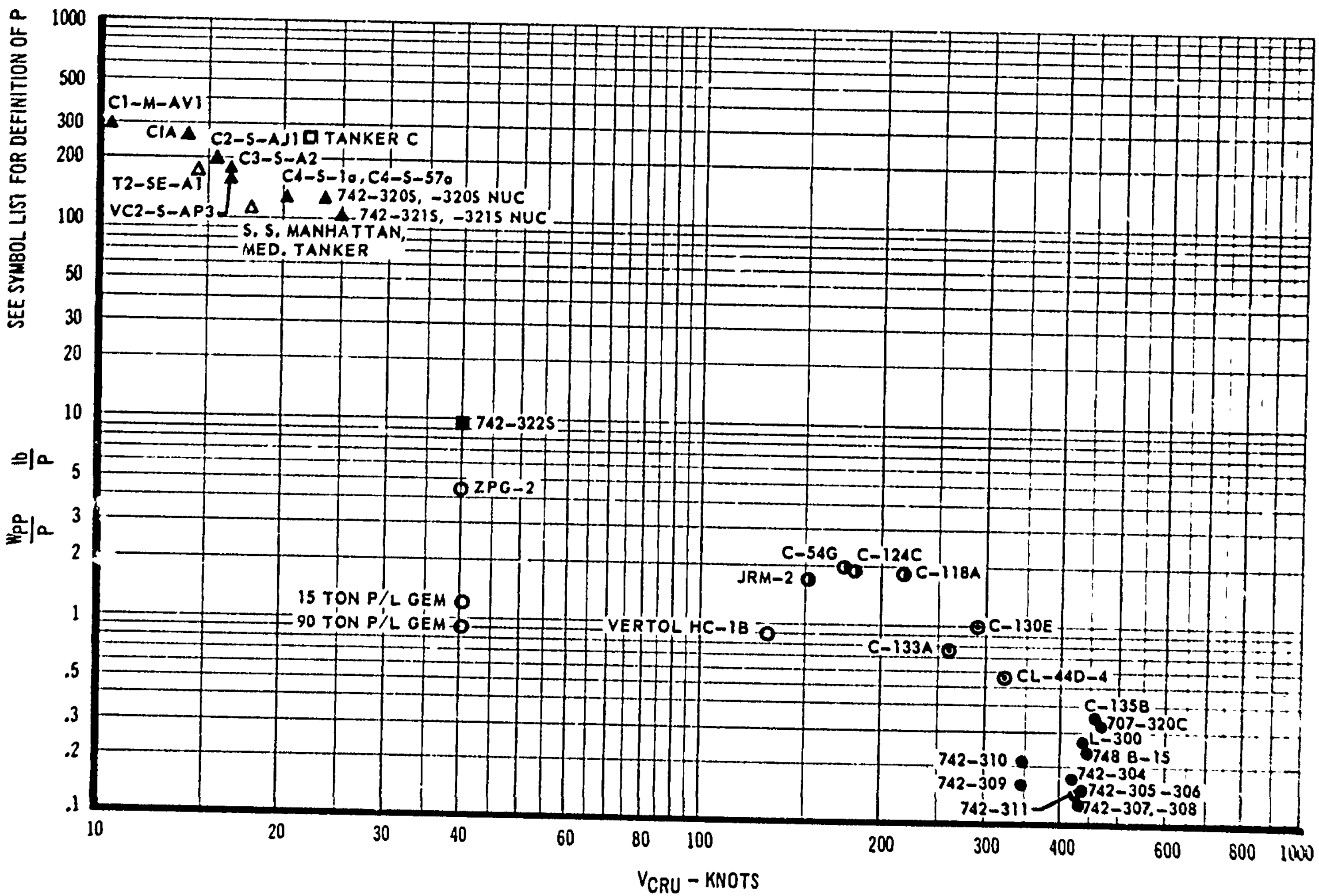

SEE SYMBOL LIST FOR DEFINITION OF P
$\frac{W_{PP}}{P}$ $\frac{lb}{P}$
1000
500
300
200
100
50
30
20
10
5
3
2
1
.5
.3
.2
.1
C1-M-AV1
CIA
C2-S-AJ1
TANKER C
C3-S-A2
T2-SE-A1
C4-S-1a, C4-S-57a
742-320S, -320S NUC
VC2-S-AP3
742-321S, -321S NUC
S. S. MANHATTAN,
MED. TANKER
742-322S
ZPG-2
C-54G
C-124C
JRM-2
C-118A
15 TON P/L GEM
90 TON P/L GEM
VERTOL HC-1B
C-130E
C-133A
CL-44D-4
C-135B
707-320C
L-300
748 B-15
742-310
742-304
742-309
742-305 -306
742-311
742-307, -308
10
20
30
40
60
80
100
200
300
400
600
800
1000
V_{CRU} - KNOTS

Fig. 18

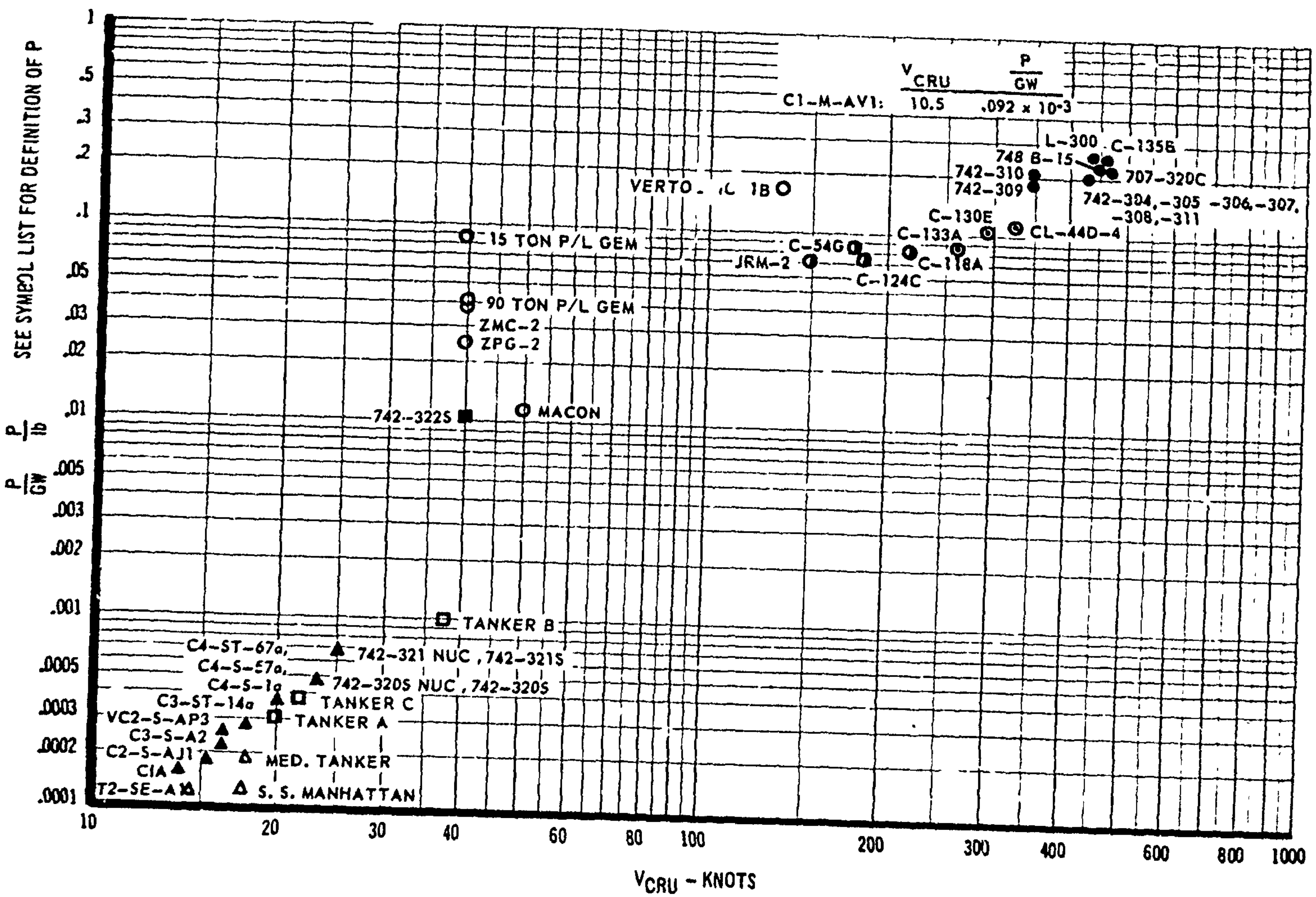
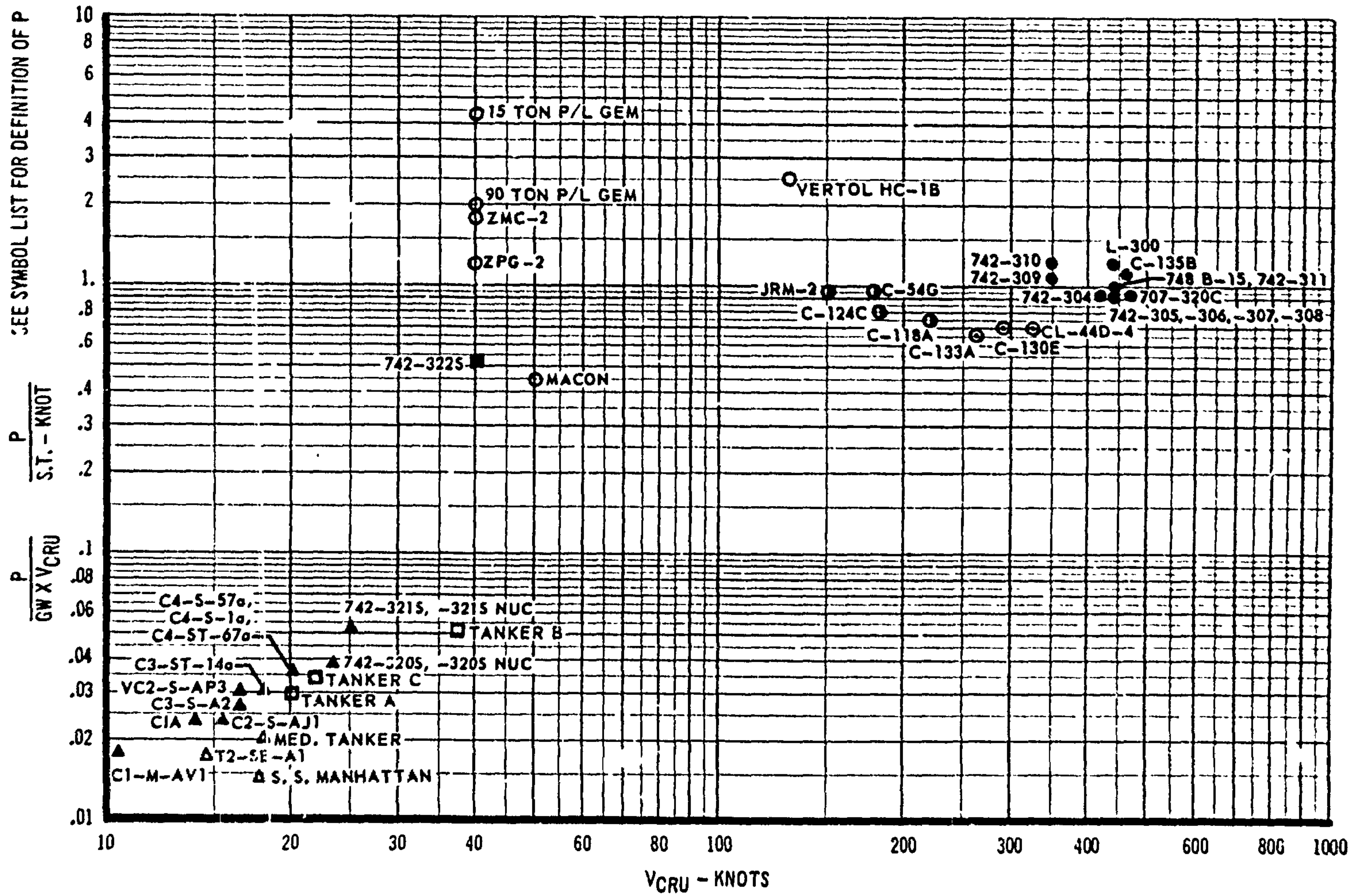
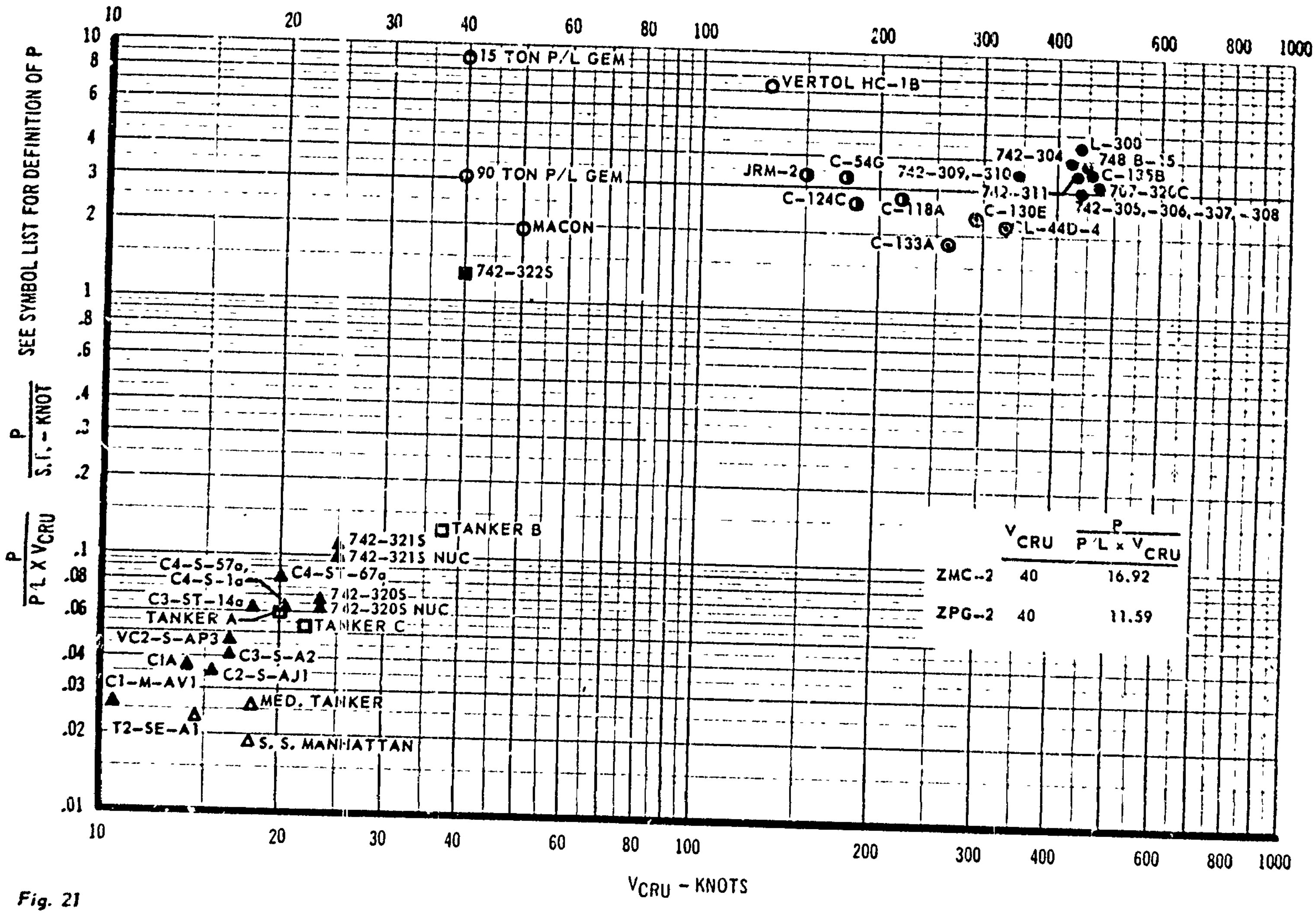

SEE SYMBOL LIST FOR DEFINITION OF P
P/GW P/lb
VCRU - KNOTS
C1-M-AV1: VCRU 10.5 P/GW .092 x 10-3
L-300
C-135B
748 B-15
742-310
742-309
707-320C
742-304,-305 -306,-307,
-308,-311
C-130E
CL-44D-4
C-133A
C-118A
C-54G
JRM-2
C-124C
15 TON P/L GEM
90 TON P/L GEM
ZMC-2
ZPG-2
742-322S
MACON
TANKER B
C4-ST-67a,
742-321 NUC, 742-321S
C4-S-57a,
742-320S NUC, 742-320S
C4-S-1a
TANKER C
C3-ST-14a
VC2-S-AP3
TANKER A
C3-S-A2
C2-S-AJ1
MED. TANKER
CIA
T2-SE-A1
S. S. MANHATTAN

Fig. 19



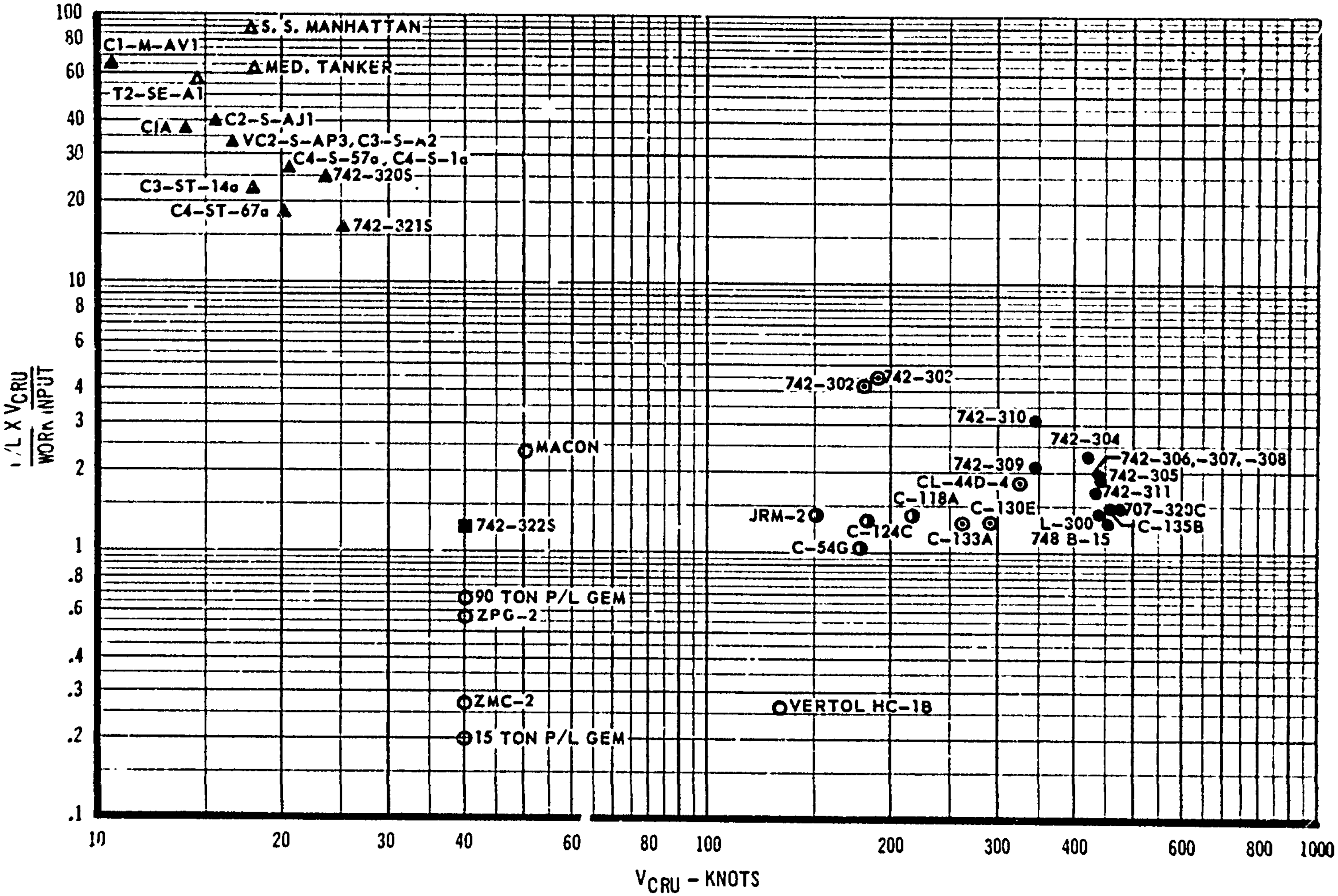
SEE SYMBOL LIST FOR DEFINITION OF P
P / S.T. - KNOT
P / GW X V_CRU
15 TON P/L GEM
90 TON P/L GEM
ZMC-2
ZPG-2
742-322S
MACON
VERTOL HC-1B
JRM-2
C-54G
C-124C
C-118A
C-133A
C-130E
CL-44D-4
742-310
742-309
742-304
L-300
C-135B
748 B-15, 742-311
707-320C
742-305, -306, -307, -308
742-321S, -321S NUC
TANKER B
742-320S, -320S NUC
TANKER C
TANKER A
C4-S-57a,
C4-S-1a,
C4-ST-67a
C3-ST-14a
VC2-S-AP3
C3-S-A2
CIA
C2-S-AJ1
MED. TANKER
T2-SE-A1
C1-M-AV1
S. S. MANHATTAN
V_CRU - KNOTS

Fig. 20



SEE SYMBOL LIST FOR DEFINITION OF P
$\frac{P}{S.T. - KNOT}$
$\frac{P}{P/L \times V_{CRU}}$
15 TON P/L GEM
90 TON P/L GEM
MACON
742-322S
VERTOL HC-1B
JRM-2
C-54G
C-124C
C-118A
C-133A
C-130E
L-44D-4
742-309, -310
742-311
742-304
L-300
748 B-15
C-135B
707-320C
742-305, -306, -307, -308
TANKER B
742-321S
742-321S NUC
C4-S-57a,
C4-S-1a
C4-ST-67a
C3-ST-14a
742-320S
742-320S NUC
TANKER A
TANKER C
VC2-S-AP3
C1A
C3-S-A2
C2-S-AJ1
C1-M-AV1
MED. TANKER
T2-SE-A1
S. S. MANHATTAN
V_{CRU} | $\frac{P}{P/L \times V_{CRU}}$
ZMC-2 40 16.92
ZPG-2 40 11.59
V_{CRU} - KNOTS

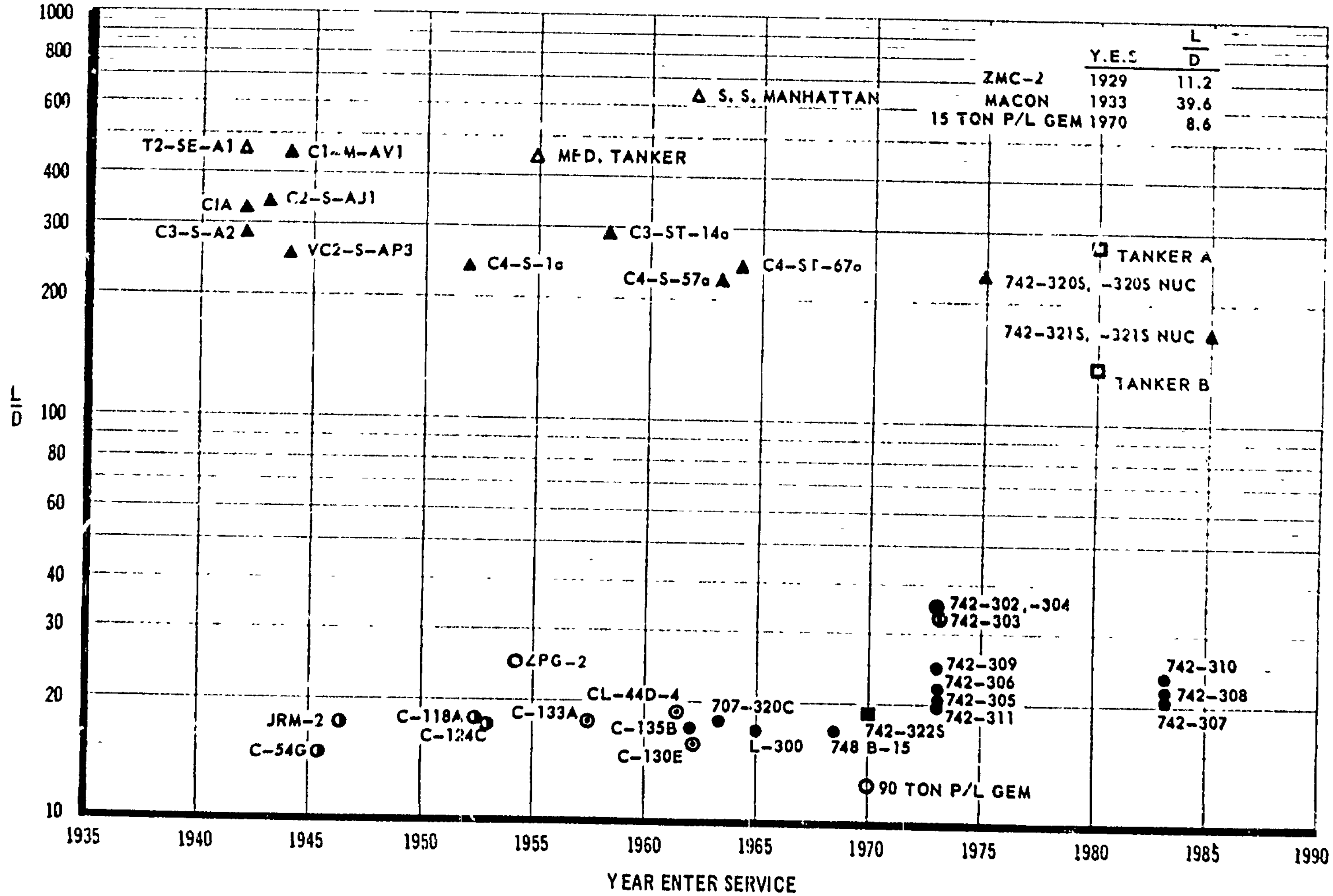
Fig. 21



S. S. MANHATTAN
C1-M-AV1
MED. TANKER
T2-SE-A1
C1A
C2-S-AJ1
VC2-S-AP3, C3-S-A2
C4-S-57a, C4-S-1a
742-320S
C3-ST-14a
C4-ST-67a
742-321S
742-302
742-303
742-310
742-304
742-306, -307, -308
742-309
742-305
CL-44D-4
742-311
C-118A
C-130E
707-320C
JRM-2
C-124C
C-133A
L-300
C-135B
748 B-15
C-54G
MACON
742-322S
90 TON P/L GEM
ZPG-2
ZMC-2
VERTOL HC-1B
15 TON P/L GEM
P/L X V CRU / WORK INPUT
V CRU - KNOTS

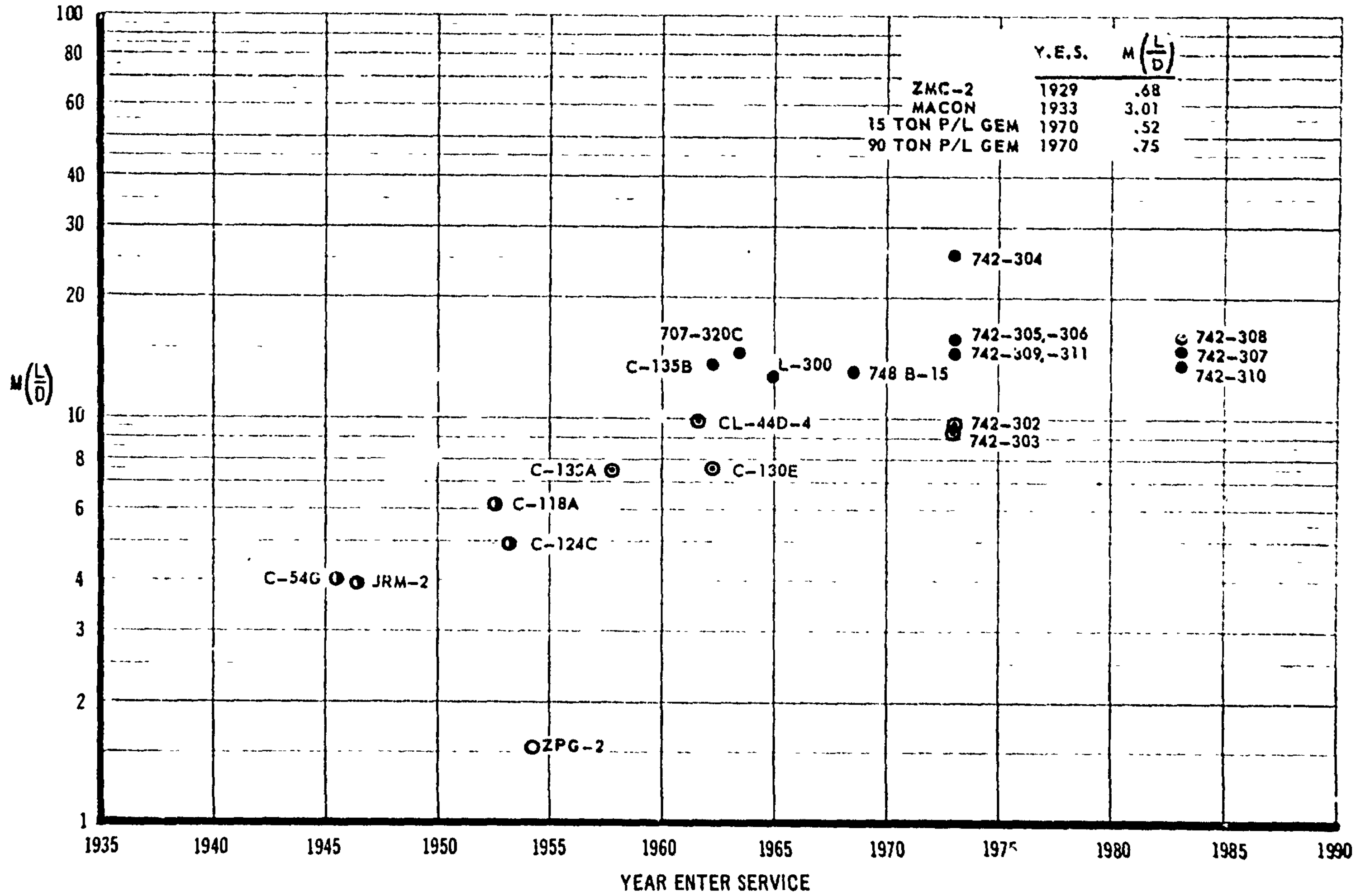
Fig. 22

3.2.2 DATA PLOTTED vs YEAR ENTER SERVICE



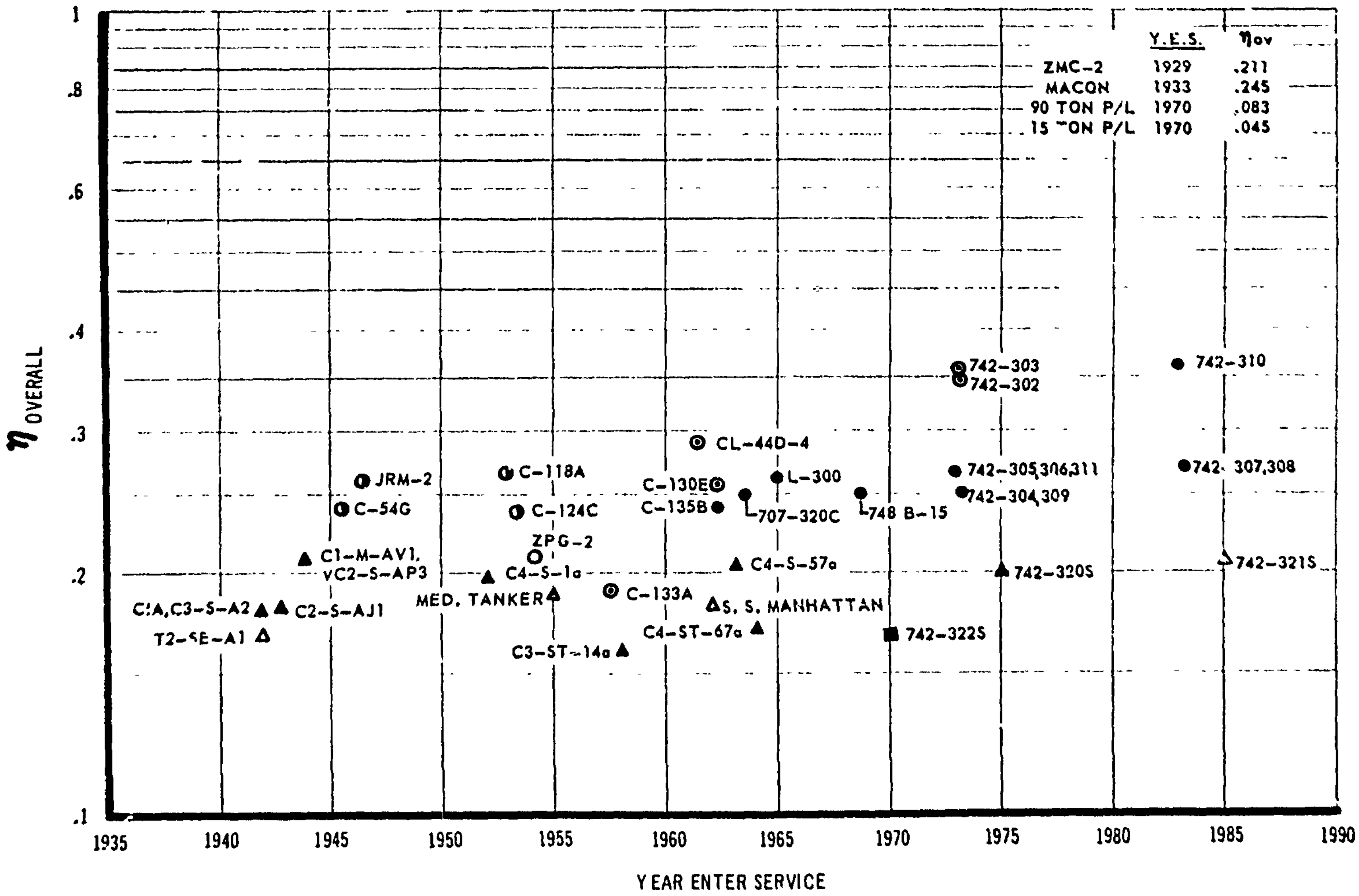
Y.E.S
L/D
ZMC-2 1929 11.2
MACON 1933 39.6
15 TON P/L GEM 1970 8.6
S. S. MANHATTAN
T2-SE-A1
C1-M-AV1
MED. TANKER
CIA
C2-S-AJ1
C3-S-A2
VC2-S-AP3
C3-ST-14a
C4-S-1a
C4-S-57a
C4-ST-67a
TANKER A
742-320S, -320S NUC
742-321S, -321S NUC
TANKER B
742-302, -304
742-303
ZPG-2
742-309
742-306
742-305
742-311
742-310
742-308
742-307
CL-44D-4
707-320C
JRM-2
C-118A
C-124C
C-133A
C-135B
C-130E
L-300
748 B-15
742-322S
C-54G
90 TON P/L GEM
L/D
YEAR ENTER SERVICE

Fig. 23



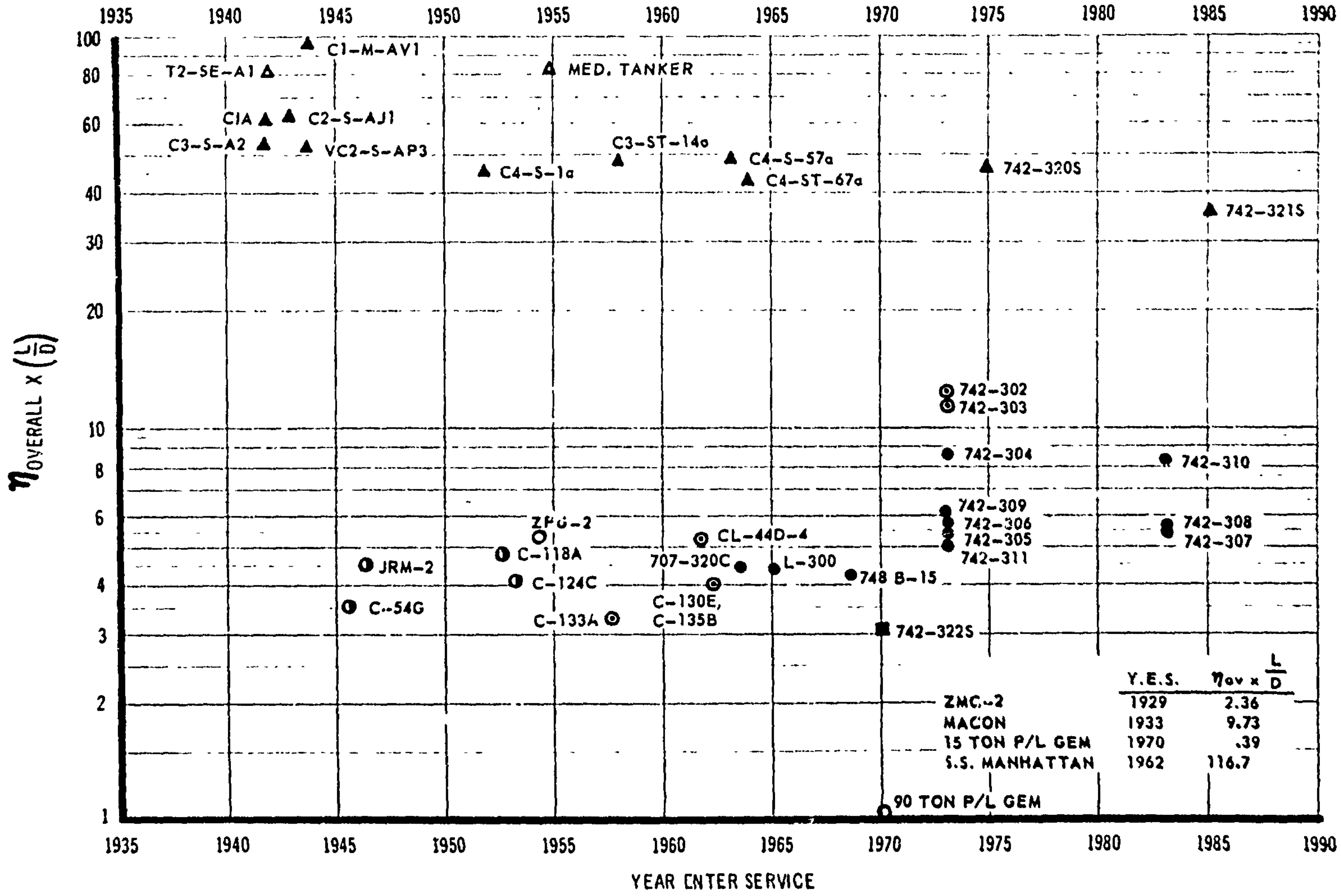
Y.E.S.
$M\left(\frac{L}{D}\right)$
ZMC-2 1929 .68
MACON 1933 3.01
15 TON P/L GEM 1970 .52
90 TON P/L GEM 1970 .75
742-304
707-320C
C-135B
L-300
748 B-15
742-305,-306
742-309,-311
742-308
742-307
742-310
CL-44D-4
742-302
742-303
C-130E
C-130A
C-118A
C-124C
C-54G
JRM-2
ZPG-2
100
80
60
40
30
20
10
8
6
4
3
2
1
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR ENTER SERVICE

Fig. 24



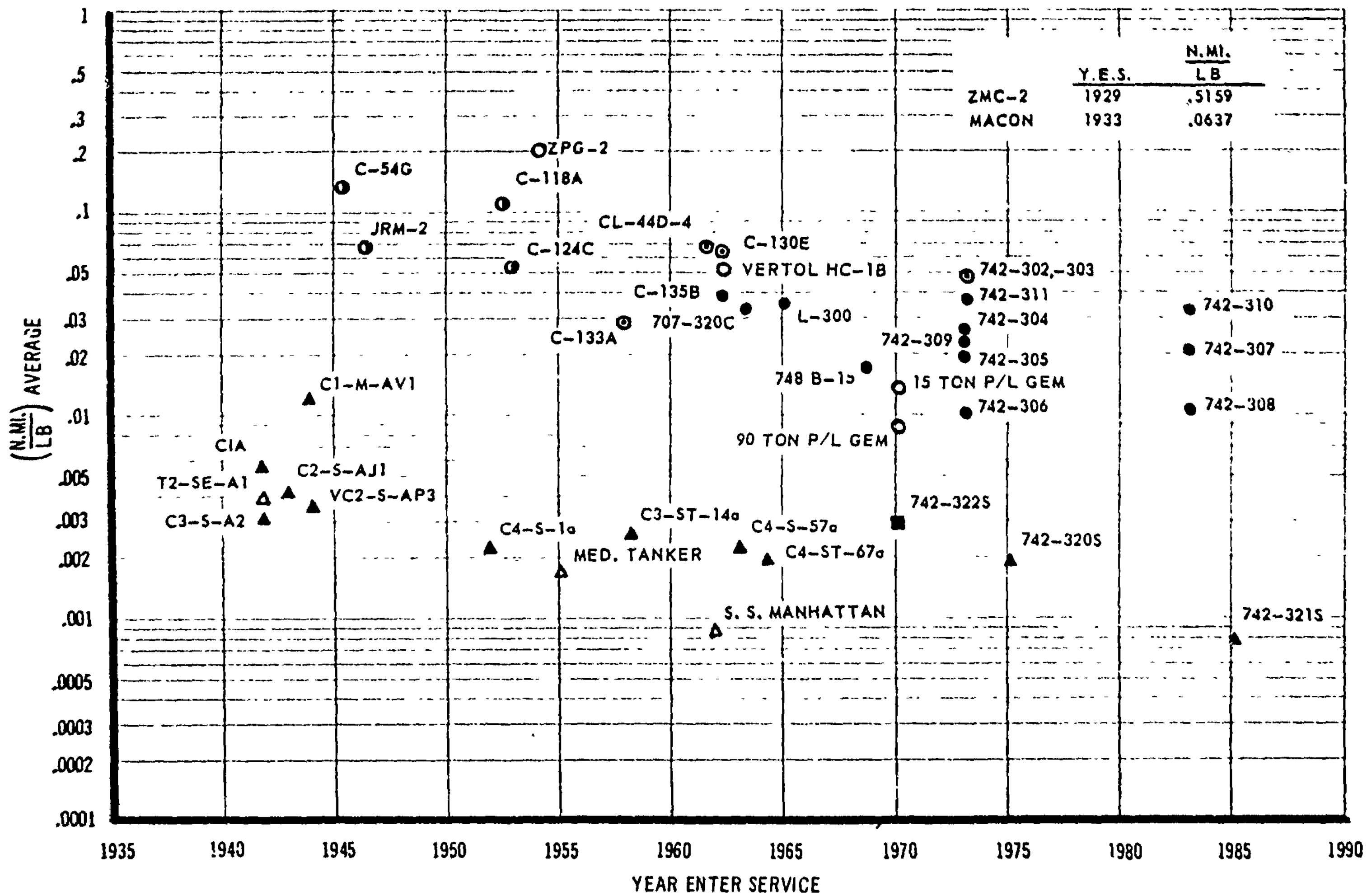
Y.E.S.
η_{ov}
ZMC-2 1929 .211
MACON 1933 .245
90 TON P/L 1970 .083
15 TON P/L 1970 .045
742-303
742-302
742-310
CL-44D-4
JRM-2
C-118A
C-130E
L-300
742-305,306,311
742. 307,308
C-54G
C-124C
C-135B
707-320C
748 B-15
742-304,309
ZPG-2
C1-M-AV1,
VC2-S-AP3
C4-S-1a
C4-S-57a
742-320S
742-321S
C1A,C3-S-A2
C2-S-AJ1
MED. TANKER
C-133A
S. S. MANHATTAN
T2-SE-A1
C4-ST-67a
742-322S
C3-ST-14a
η OVERALL
YEAR ENTER SERVICE

Fig. 25



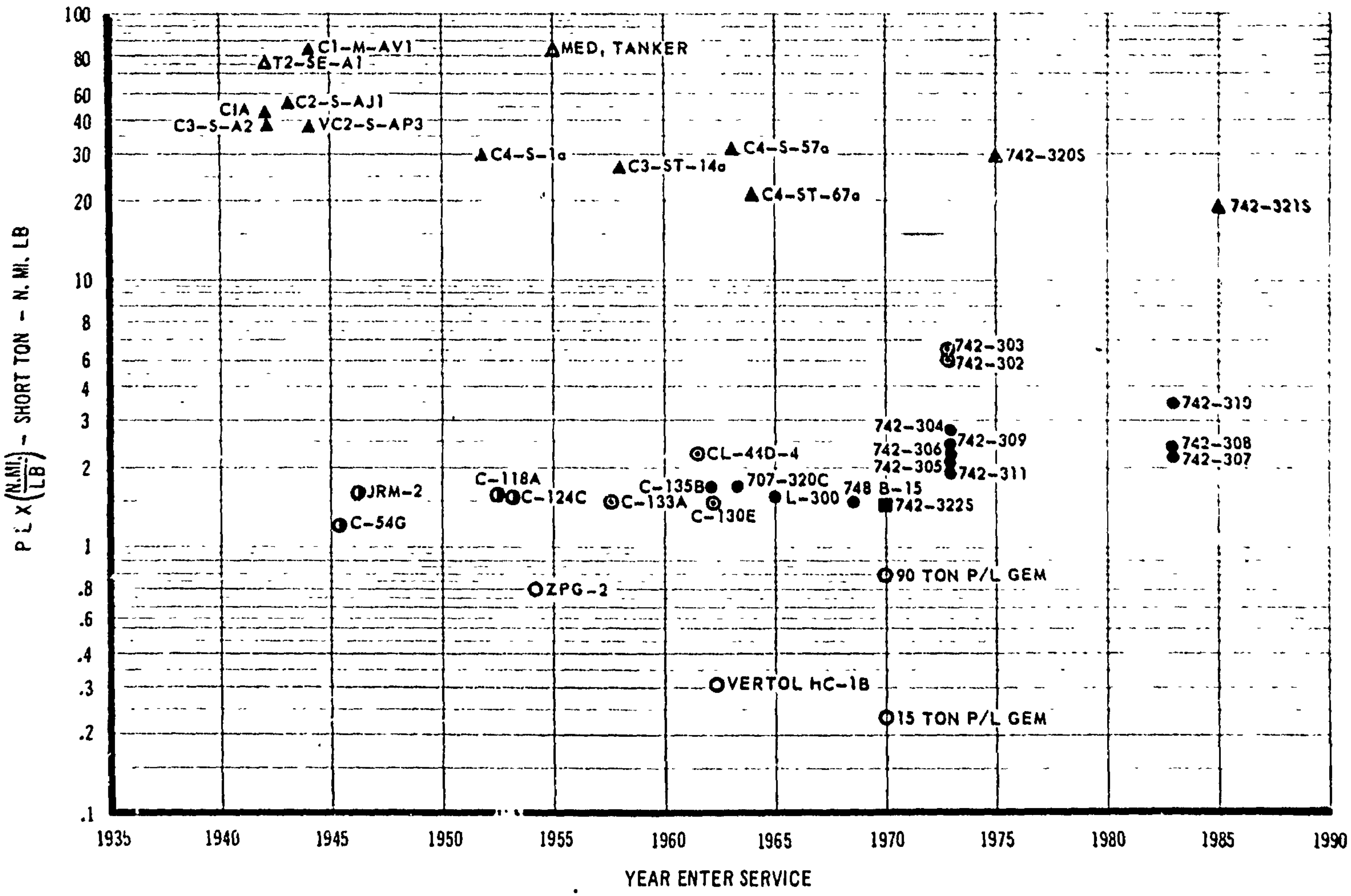
$\eta_{OVERALL} \times \left(\frac{L}{D}\right)$
YEAR ENTER SERVICE
C1-M-AV1
T2-SE-A1
MED. TANKER
CIA
C2-S-AJ1
C3-S-A2
VC2-S-AP3
C3-ST-14a
C4-S-57a
C4-S-1a
C4-ST-67a
742-320S
742-321S
742-302
742-303
742-304
742-310
742-309
742-306
742-305
742-311
742-308
742-307
ZPG-2
CL-44D-4
JRM-2
C-118A
707-320C
L-300
C-124C
748 B-15
C-54G
C-133A
C-130E,
C-135B
742-322S
Y.E.S.
$\eta_{ov} \times \frac{L}{D}$
ZMC-2 1929 2.36
MACON 1933 9.73
15 TON P/L GEM 1970 .39
S.S. MANHATTAN 1962 116.7
90 TON P/L GEM

Fig. 26



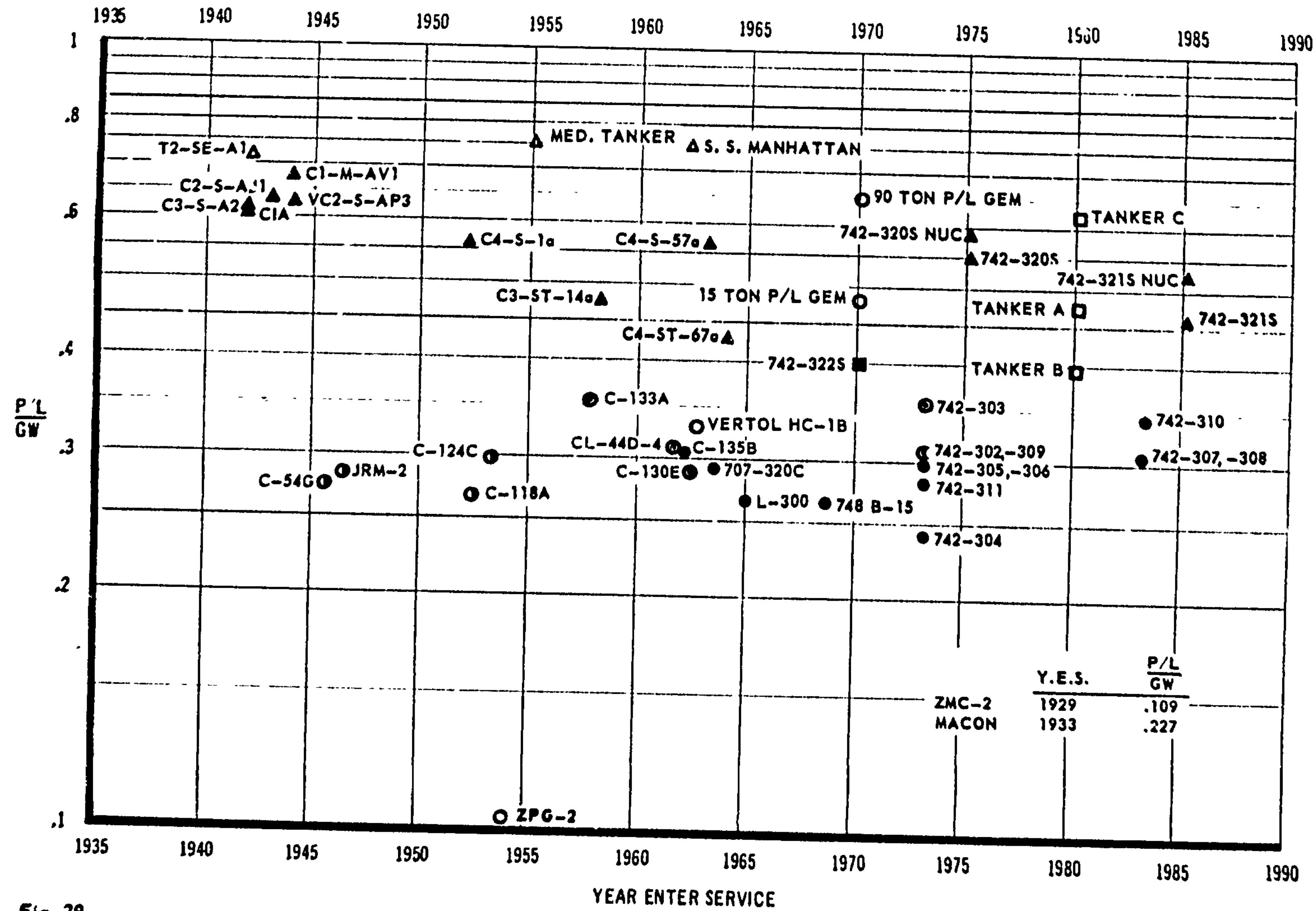
Y.E.S.
N.MI./LB
ZMC-2 1929 .5159
MACON 1933 .0637
ZPG-2
C-54G
C-118A
JRM-2
CL-44D-4
C-130E
C-124C
VERTOL HC-1B
742-302,-303
C-135B
742-311
707-320C
L-300
742-310
742-304
C-133A
742-309
742-307
742-305
748 B-15
15 TON P/L GEM
C1-M-AV1
742-306
742-308
90 TON P/L GEM
C1A
C2-S-AJ1
T2-SE-A1
VC2-S-AP3
C3-S-A2
742-322S
C3-ST-14a
C4-S-57a
C4-S-1a
742-320S
MED. TANKER
C4-ST-67a
S. S. MANHATTAN
742-321S
(N.MI./LB) AVERAGE
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.0005
.0003
.0002
.0001
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR ENTER SERVICE

Fig. 27



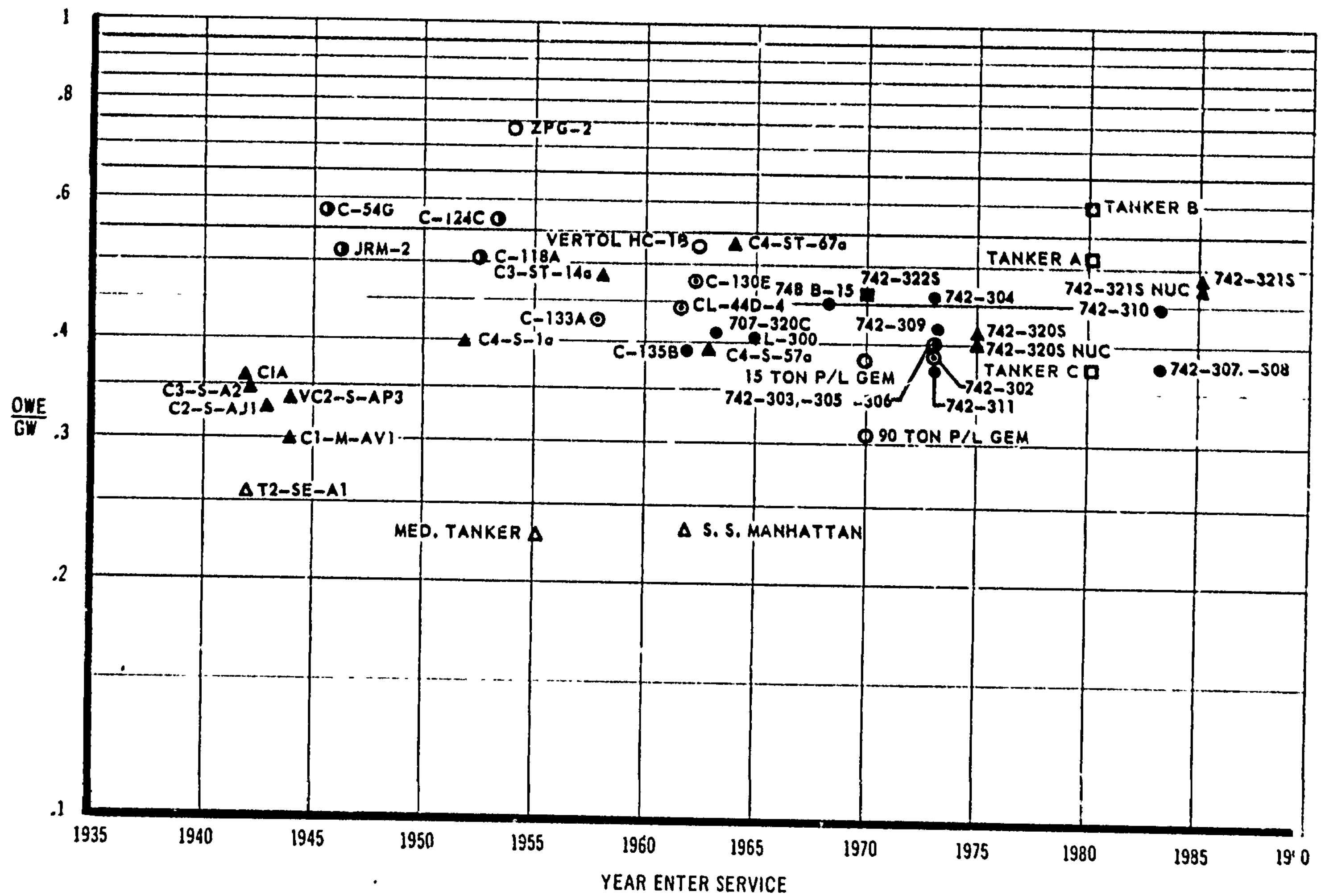
C1-M-AV1
T2-SE-A1
MED. TANKER
C1A
C2-S-AJ1
C3-S-A2
VC2-S-AP3
C4-S-1a
C3-ST-14a
C4-S-57a
C4-ST-67a
742-320S
742-321S
742-303
742-302
742-310
742-304
742-309
742-306
742-308
742-307
742-305
742-311
CL-44D-4
C-118A
C-135B
707-320C
748
B-15
JRM-2
C-124C
C-133A
L-300
742-322S
C-130E
C-54G
90 TON P/L GEM
ZPG-2
VERTOL HC-1B
15 TON P/L GEM
100
80
60
40
30
20
10
8
6
4
3
2
1
.8
.6
.4
.3
.2
.1
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR ENTER SERVICE
P L X (N.MI./LB) - SHORT TON - N. MI. LB

Fig. 28



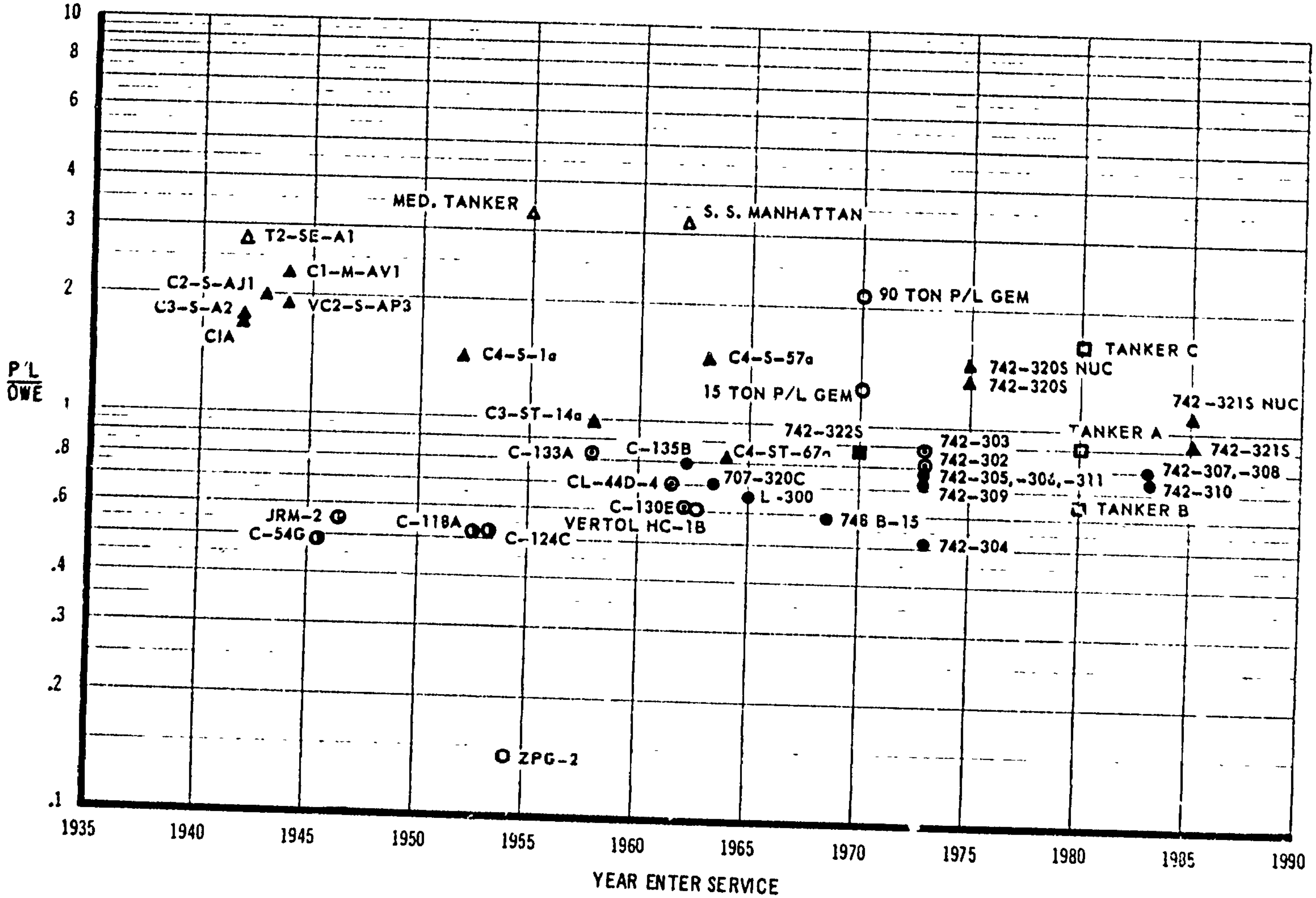
P/L / GW
YEAR ENTER SERVICE
T2-SE-A1
MED. TANKER
S. S. MANHATTAN
C1-M-AV1
C2-S-A1
VC2-S-AP3
C3-S-A2
C1A
90 TON P/L GEM
TANKER C
C4-S-1a
C4-S-57a
742-320S NUC
742-320S
742-321S NUC
C3-ST-14a
15 TON P/L GEM
TANKER A
742-321S
C4-ST-67a
742-322S
TANKER B
C-133A
VERTOL HC-1B
742-303
742-310
C-124C
CL-44D-4
C-135B
742-302, -309
742-307, -308
C-54G
JRM-2
C-130E
707-320C
742-305, -306
C-118A
L-300
748 B-15
742-311
742-304
Y.E.S.
P/L / GW
ZMC-2
MACON
1929
1933
.109
.227
ZPG-2

Fig. 29



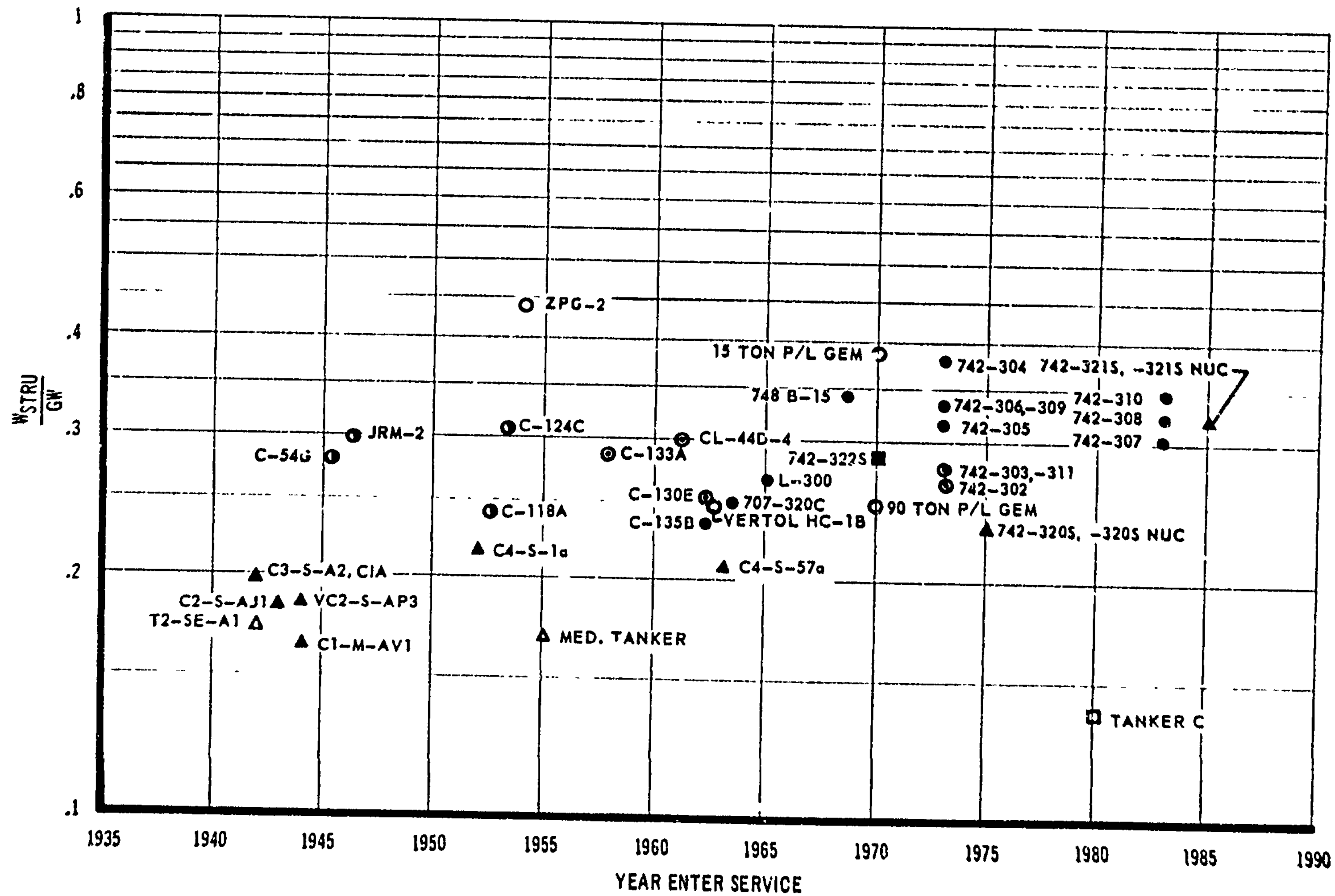
ZPG-2
C-54G
C-124C
JRM-2
C-118A
C3-ST-14a
VERTOL HC-1B
C4-ST-67a
C-130E
748 B-15
742-322S
CL-44D-4
742-304
C-133A
707-320C
L-300
C4-S-1a
C-135B
C4-S-57a
742-309
15 TON P/L GEM
742-303,-305
-306
742-302
742-311
90 TON P/L GEM
742-320S
742-320S NUC
TANKER C
TANKER A
TANKER B
742-321S NUC
742-321S
742-310
742-307, -308
CIA
C3-S-A2
C2-S-AJ1
VC2-S-AP3
C1-M-AV1
T2-SE-A1
MED. TANKER
S. S. MANHATTAN
OWE/GW
YEAR ENTER SERVICE

Fig. 30



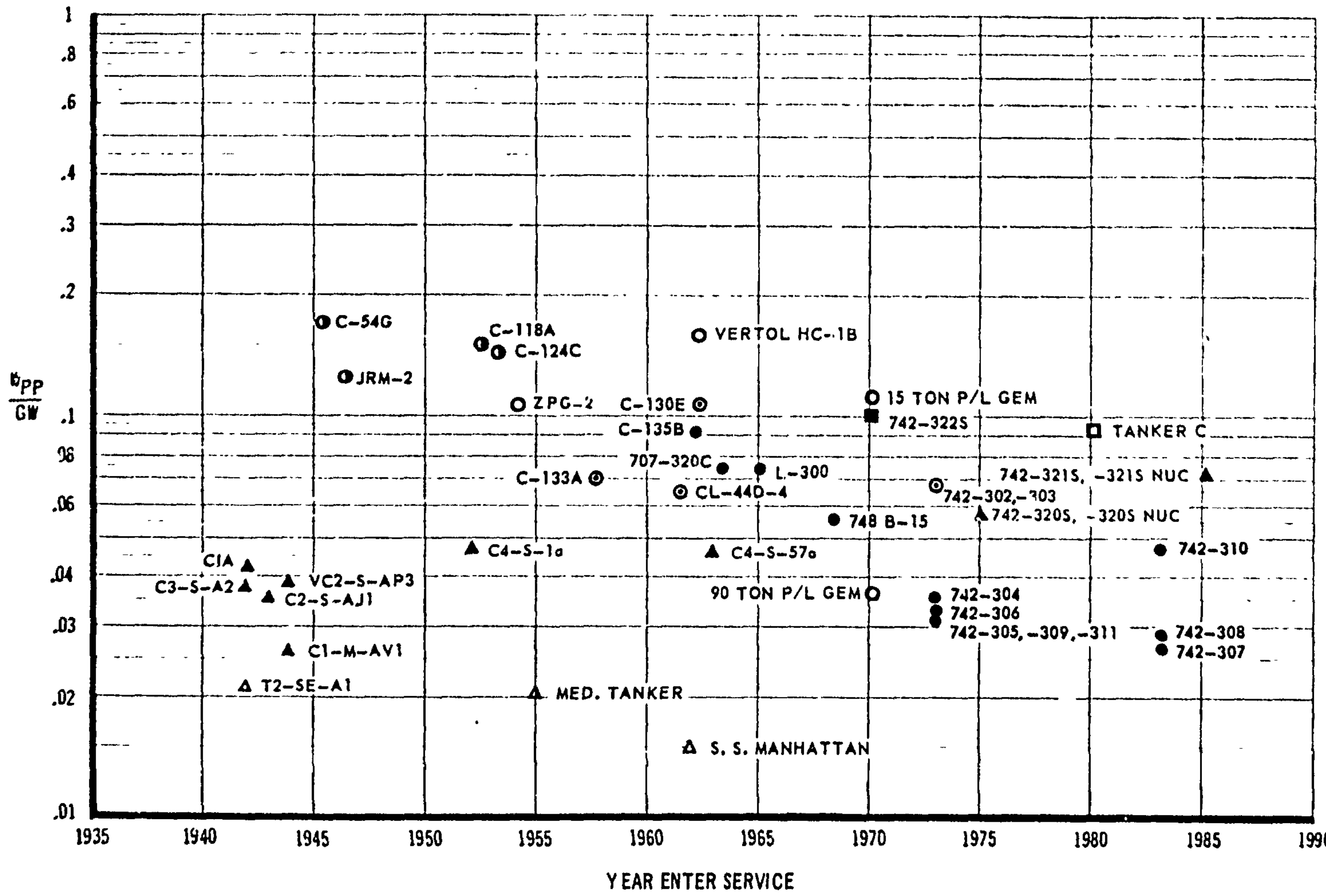
P/L / OWE
10
8
6
4
3
2
1
.8
.6
.4
.3
.2
.1
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR ENTER SERVICE
T2-SE-A1
C1-M-AV1
C2-S-AJ1
C3-S-A2
VC2-S-AP3
CIA
MED. TANKER
S. S. MANHATTAN
90 TON P/L GEM
C4-S-1a
C4-S-57a
15 TON P/L GEM
TANKER C
742-320S NUC
742-320S
742-321S NUC
C3-ST-14a
742-322S
TANKER A
742-321S
C-133A
C-135B
C4-ST-67a
742-303
742-302
742-305, -304, -311
742-309
742-307, -308
742-310
CL-44D-4
707-320C
L-300
C-130E
VERTOL HC-1B
TANKER B
JRM-2
C-54G
C-118A
C-124C
748 B-15
742-304
ZPG-2

Fig. 31



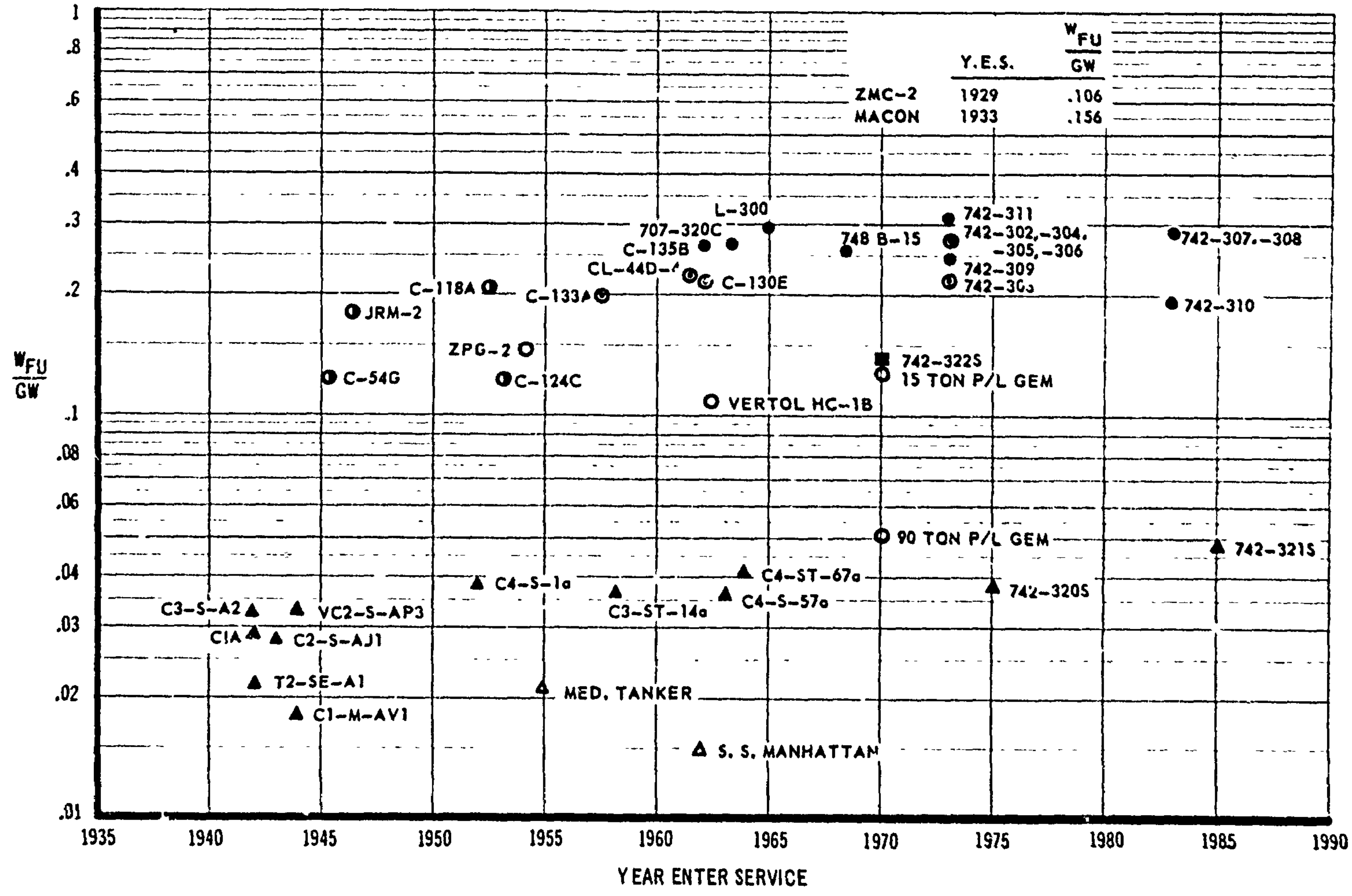
1
.8
.6
.4
.3
.2
.1
W_{STRU}/GW
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR ENTER SERVICE
ZPG-2
15 TON P/L GEM
742-304
742-321S, -321S NUC
748 B-15
742-306,-309
742-310
742-308
742-305
742-307
JRM-2
C-124C
CL-44D-4
C-54G
C-133A
742-322S
742-303,-311
742-302
L-300
C-130E
707-320C
90 TON P/L GEM
C-118A
C-135B
VERTOL HC-1B
742-320S, -320S NUC
C4-S-1a
C4-S-57a
C3-S-A2, CIA
C2-S-AJ1
VC2-S-AP3
T2-SE-A1
C1-M-AV1
MED. TANKER
TANKER C

Fig. 32



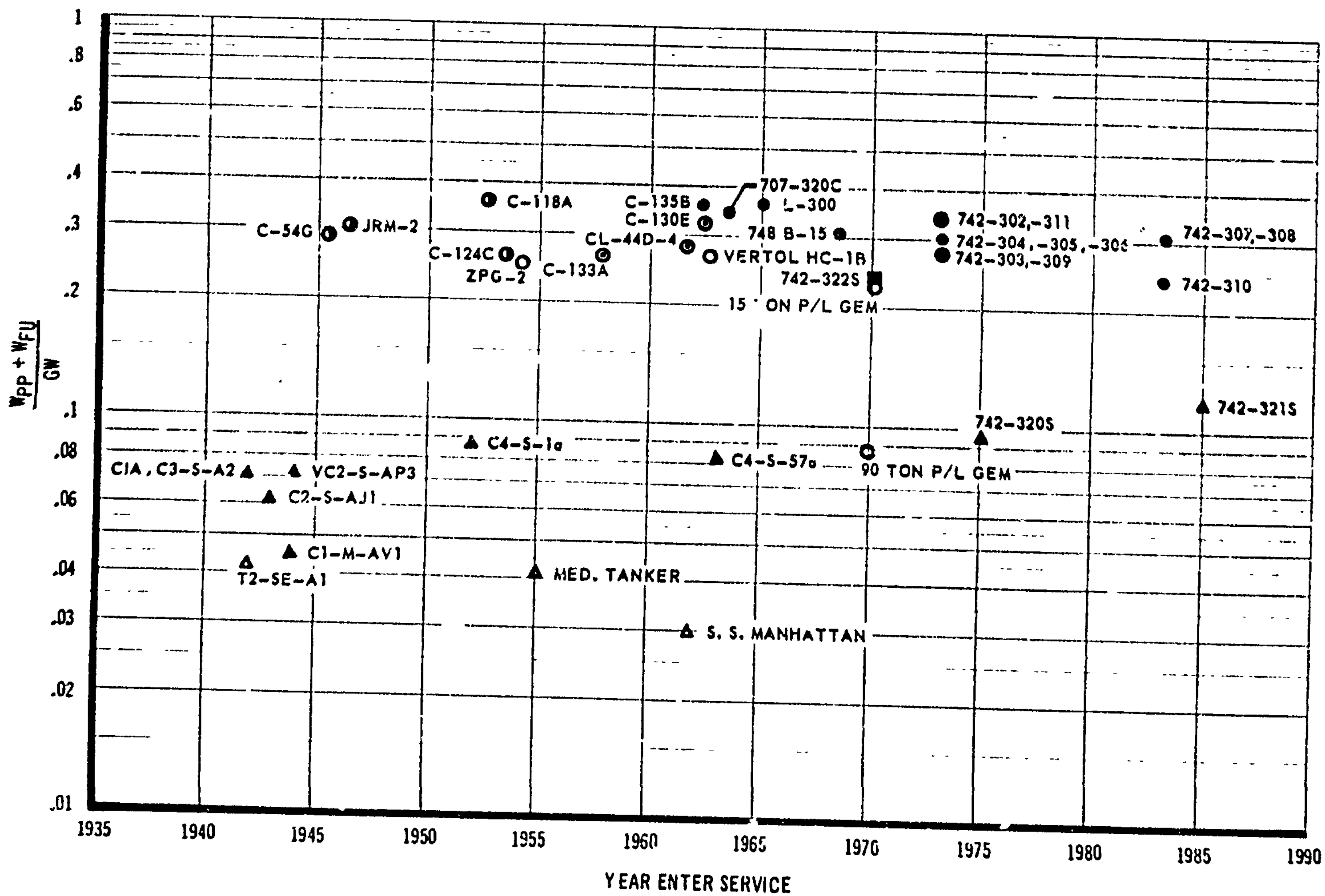
C-54G
JRM-2
C-118A
C-124C
ZPG-2
C-130E
C-135B
C-133A
707-320C
L-300
CL-44D-4
VERTOL HC-1B
15 TON P/L GEM
742-322S
TANKER C
742-321S, -321S NUC
742-302,-303
742-320S, -320S NUC
748 B-15
742-310
C1A
C3-S-A2
VC2-S-AP3
C2-S-AJ1
C4-S-1a
C4-S-57a
90 TON P/L GEM
742-304
742-306
742-305,-309,-311
742-308
742-307
C1-M-AV1
T2-SE-A1
MED. TANKER
S. S. MANHATTAN
$\frac{W_{PP}}{GW}$
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR ENTER SERVICE

Fig. 33



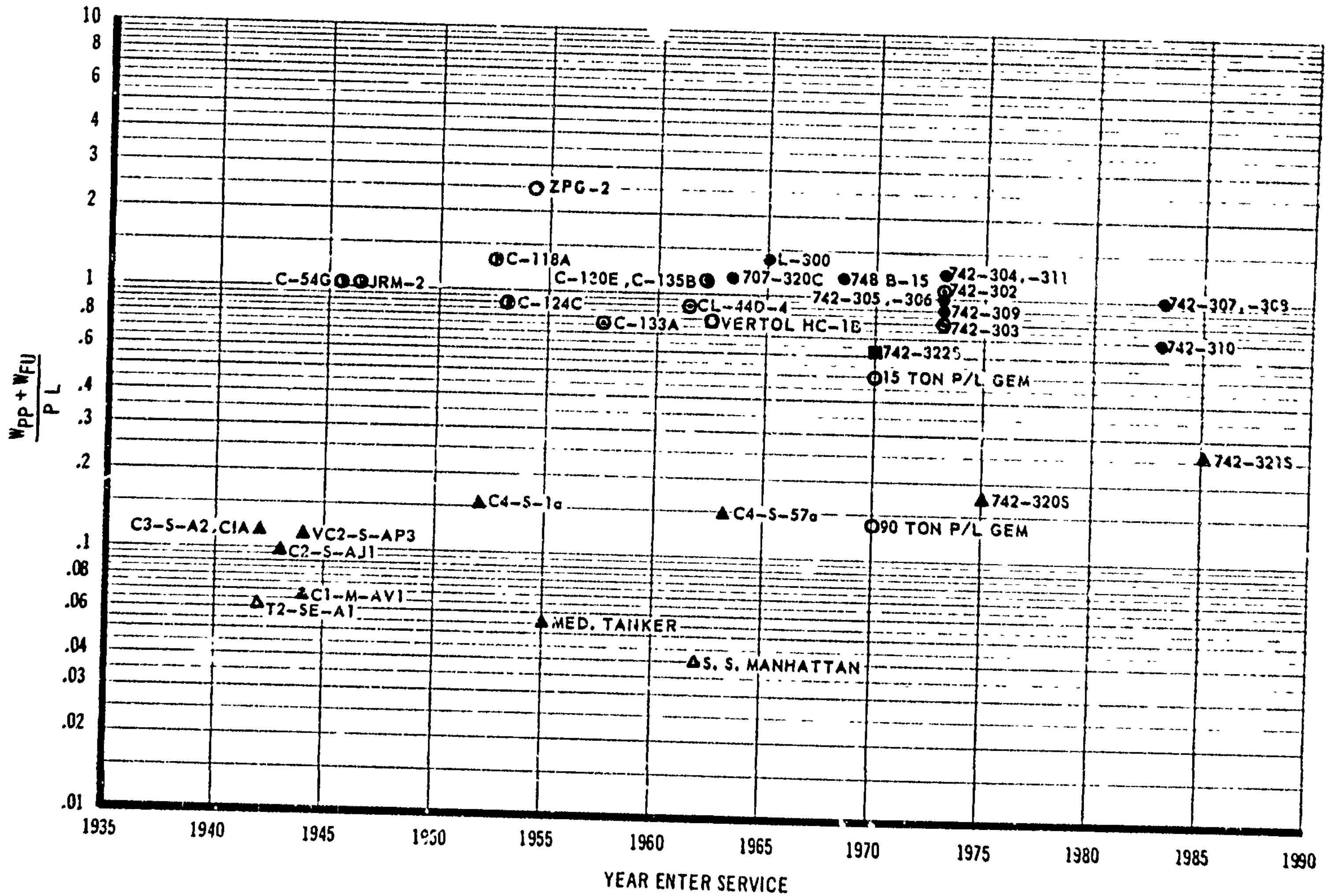
Y.E.S.
$\frac{W_{FU}}{GW}$
ZMC-2 1929 .106
MACON 1933 .156
C3-S-A2
C1A
T2-SE-A1
C1-M-AV1
VC2-S-AP3
C2-S-AJ1
C-54G
JRM-2
C-118A
ZPG-2
C-124C
C4-S-1a
C-133A
MED. TANKER
C3-ST-14a
CL-44D-4
C-135B
707-320C
C-130E
VERTOL HC-1B
S. S. MANHATTAN
C4-S-57a
C4-ST-67a
L-300
748 B-15
742-322S
15 TON P/L GEM
90 TON P/L GEM
742-311
742-302,-304,
-305,-306
742-309
742-303
742-320S
742-307,-308
742-310
742-321S
$\frac{W_{FU}}{GW}$
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR ENTER SERVICE

Fig. 34



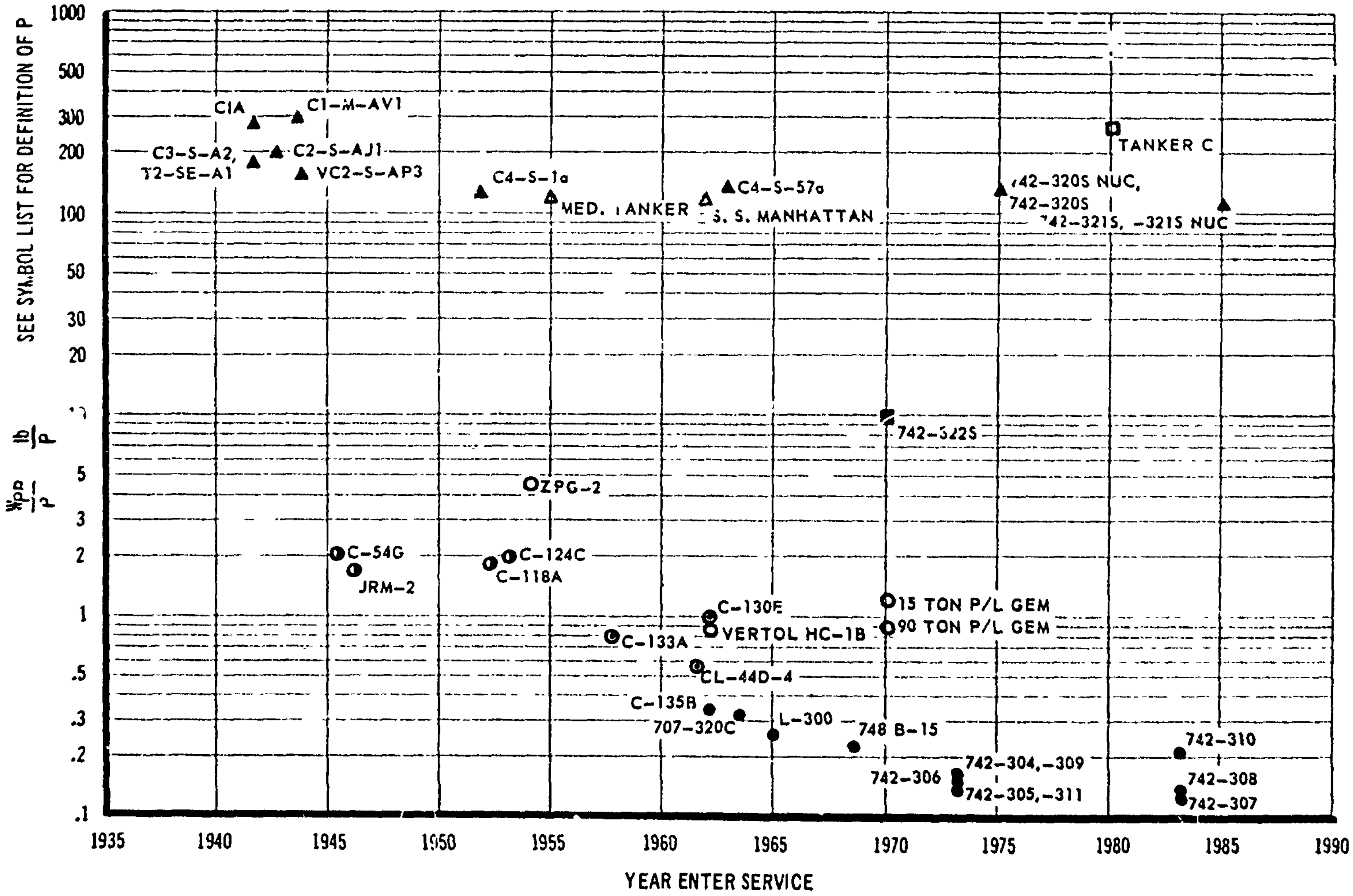
$\frac{W_{PP} + W_{FU}}{GW}$
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR ENTER SERVICE
C-54G
JRM-2
C-118A
C-124C
ZPG-2
C-133A
CL-44D-4
C-135B
C-130E
707-320C
L-300
748 B-15
VERTOL HC-1B
742-322S
15 ON P/L GEM
742-302,-311
742-304,-305,-306
742-303,-309
742-307,-308
742-310
742-321S
742-320S
90 TON P/L GEM
C4-S-1a
C4-S-57a
CIA, C3-S-A2
VC2-S-AP3
C2-S-AJ1
C1-M-AV1
T2-SE-A1
MED. TANKER
S. S. MANHATTAN

Fig. 35



$\frac{W_{PP} + W_{FU}}{P\,L}$
10
8
6
4
3
2
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
YEAR ENTER SERVICE
ZPG-2
C-118A
C-54G
JRM-2
C-124C
C-130E, C-135B
C-133A
CL-44D-4
VERTOL HC-1B
L-300
707-320C
748 B-15
742-304, -311
742-302
742-305, -306
742-309
742-303
742-3225
15 TON P/L GEM
742-307, -309
742-310
742-321S
742-320S
90 TON P/L GEM
C4-S-1a
C4-S-57a
C3-S-A2, C1A
VC2-S-AP3
C2-S-AJ1
C1-M-AV1
T2-SE-A1
MED. TANKER
S. S. MANHATTAN

Fig. 36



SEE SYMBOL LIST FOR DEFINITION OF P
CIA
C1-M-AV1
C3-S-A2,
T2-SE-A1
C2-S-AJ1
VC2-S-AP3
C4-S-1a
MED. TANKER
C4-S-57a
S. S. MANHATTAN
742-320S NUC,
742-320S
742-321S, -321S NUC
TANKER C
742-322S
ZPG-2
C-54G
JRM-2
C-124C
C-118A
C-130E
VERTOL HC-1B
C-133A
CL-44D-4
15 TON P/L GEM
90 TON P/L GEM
C-135B
707-320C
L-300
748 B-15
742-306
742-304, -309
742-305, -311
742-310
742-308
742-307
YEAR ENTER SERVICE

Fig. 37

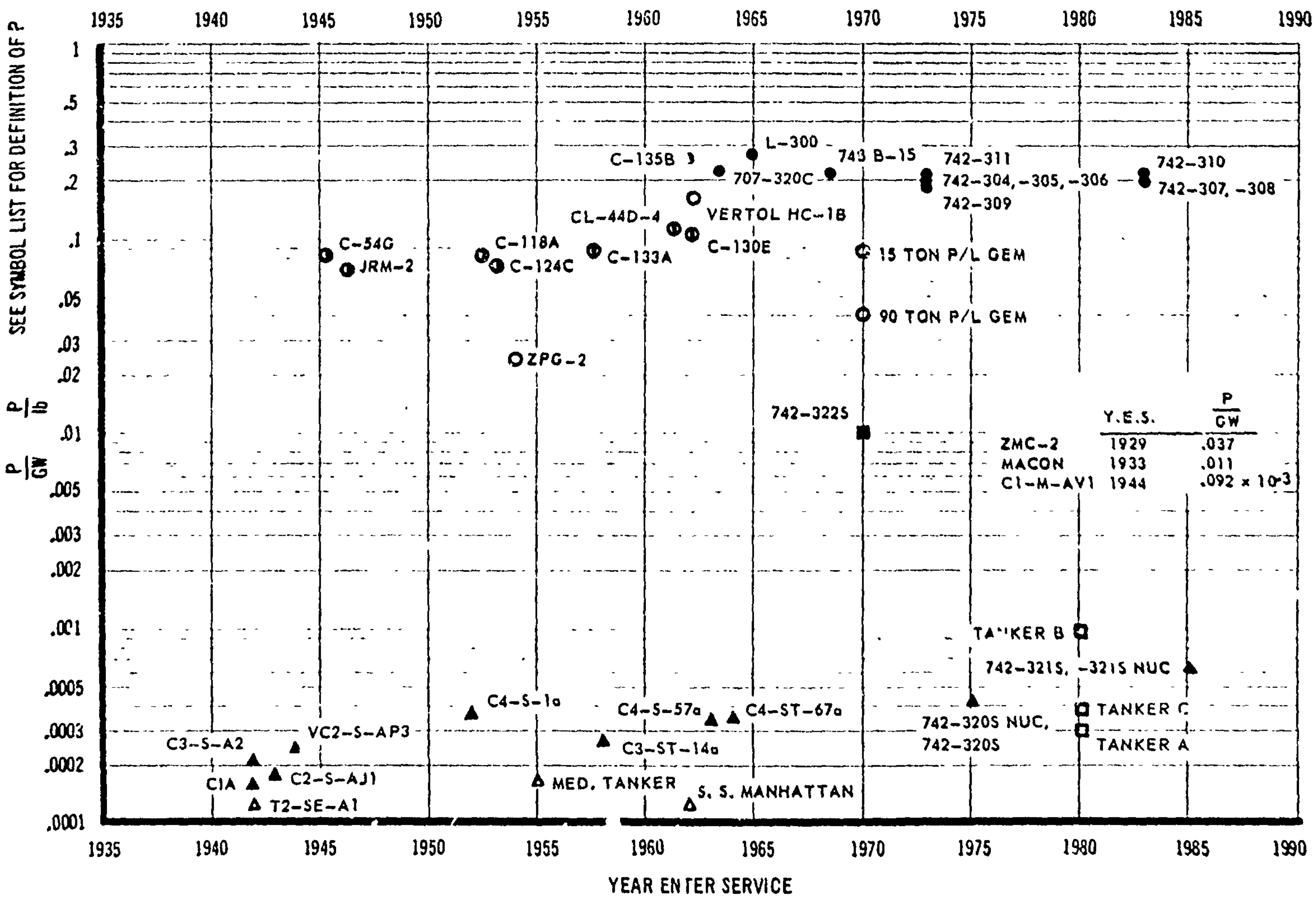
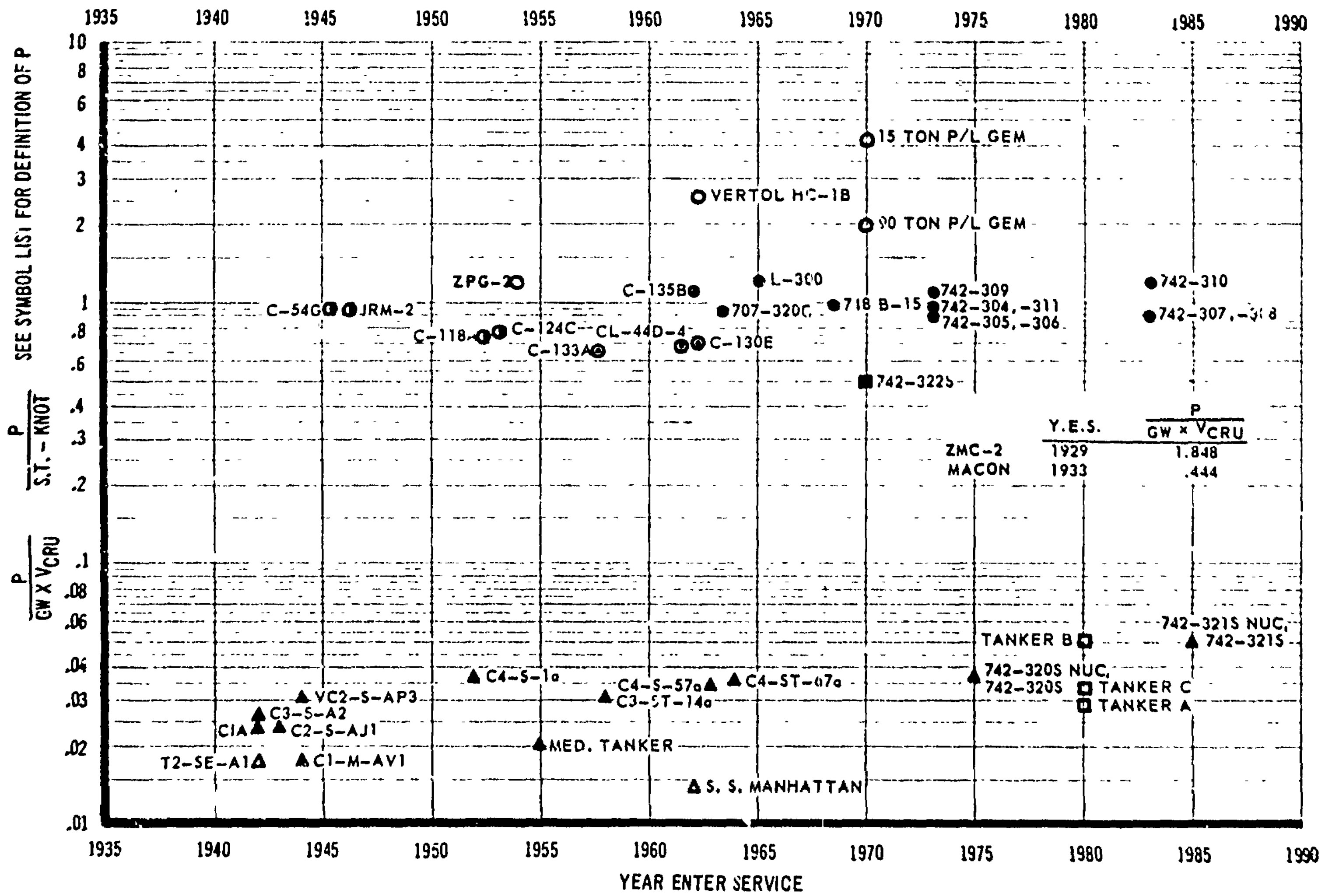
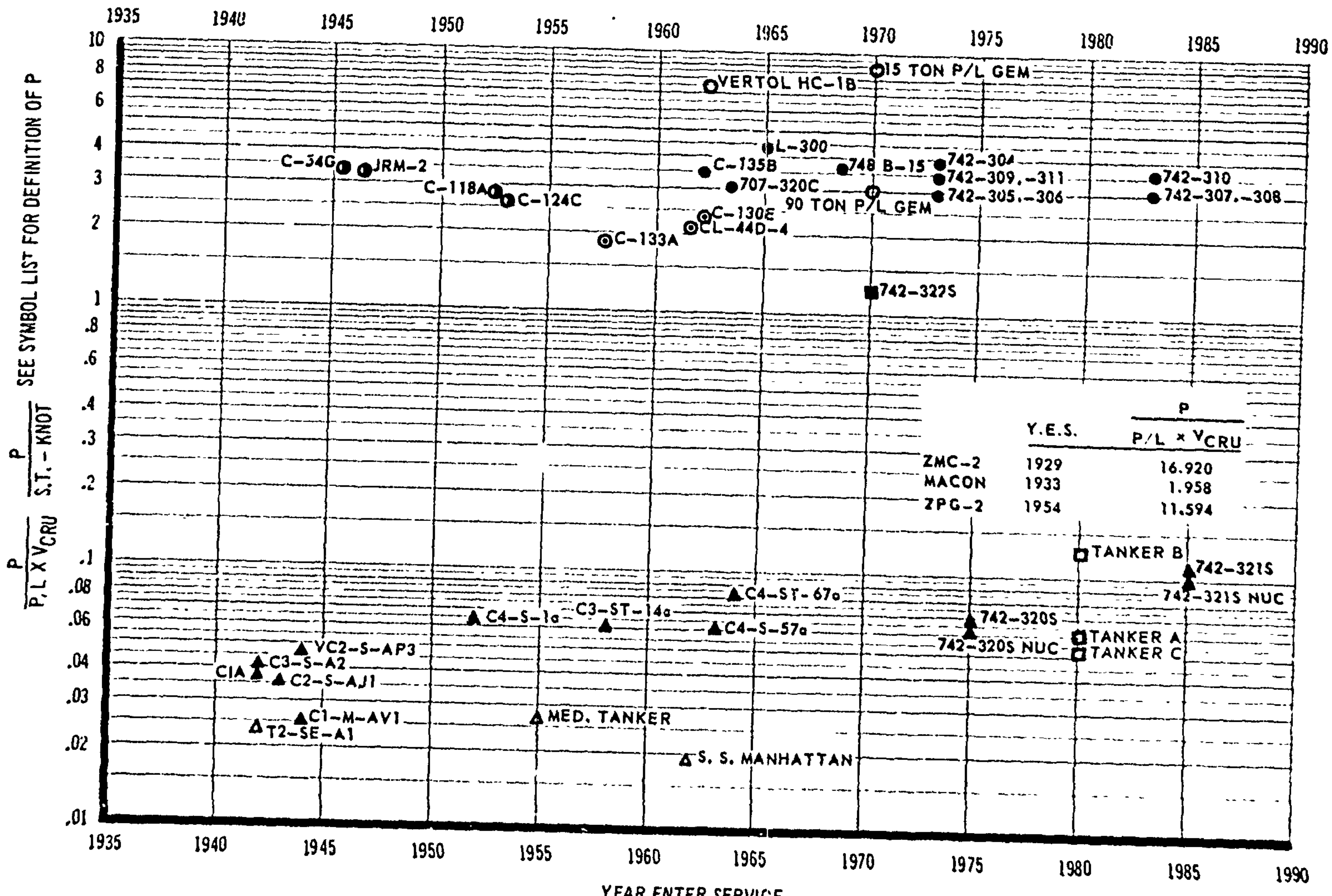

SEE SYMBOL LIST FOR DEFINITION OF P
$\frac{P}{GW}$
$\frac{P}{lb}$
YEAR ENTER SERVICE
C-54G
JRM-2
C-118A
C-124C
ZPG-2
C-133A
CL-44D-4
C-135B
C-130E
VERTOL HC-1B
L-300
707-320C
743 B-15
742-311
742-304, -305, -306
742-309
742-310
742-307, -308
15 TON P/L GEM
90 TON P/L GEM
742-322S
Y.E.S.
ZMC-2 1929 .037
MACON 1933 .011
C1-M-AV1 1944 .092 x 10-3
TANKER B
742-321S, -321S NUC
TANKER C
TANKER A
742-320S NUC,
742-320S
C3-S-A2
C1A
T2-SE-A1
C2-S-AJ1
VC2-S-AP3
C4-S-1a
MED. TANKER
C3-ST-14a
C4-S-57a
C4-ST-67a
S. S. MANHATTAN

Fig. 38



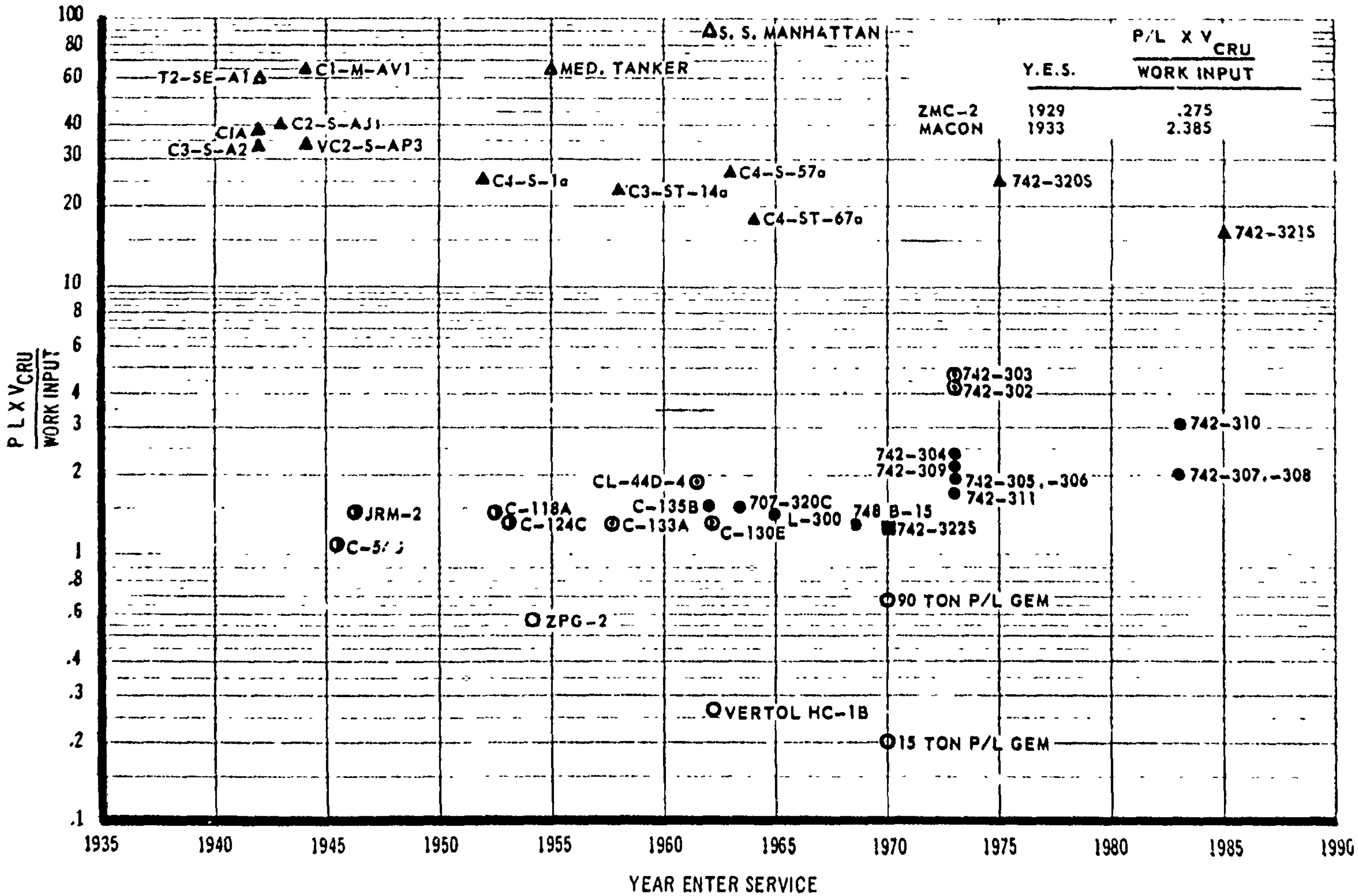
SEE SYMBOL LIST FOR DEFINITION OF P
$\frac{P}{S.T. - KNOT}$
$\frac{P}{GW \times V_{CRU}}$
15 TON P/L GEM
VERTOL HC-1B
90 TON P/L GEM
ZPG-2
C-135B
L-300
742-309
742-310
C-54G
JRM-2
707-320C
718 B-15
742-304, -311
742-305, -306
742-307, -308
C-118
C-124C
CL-44D-4
C-130E
C-133A
742-322S
Y.E.S.
ZMC-2 1929 1.848
MACON 1933 .444
742-321S NUC,
742-321S
TANKER B
742-320S NUC,
742-320S
TANKER C
TANKER A
C4-S-1a
C4-S-57a
C4-ST-67a
C3-ST-14a
VC2-S-AP3
C3-S-A2
C1A
C2-S-AJ1
MED. TANKER
T2-SE-A1
C1-M-AV1
S. S. MANHATTAN
YEAR ENTER SERVICE

Fig. 39



SEE SYMBOL LIST FOR DEFINITION OF P
$\frac{P}{P/L \times V_{CRU}}$ $\frac{P}{S.T. - KNOT}$
YEAR ENTER SERVICE
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
10
8
6
4
3
2
1
.8
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
15 TON P/L GEM
VERTOL HC-1B
L-300
C-34G
JRM-2
C-135B
748 B-15
742-304
742-309, -311
742-310
C-118A
C-124C
707-320C
742-305, -306
742-307, -308
C-130E
90 TON P/L GEM
CL-44D-4
C-133A
742-322S
Y.E.S.
$\frac{P}{P/L \times V_{CRU}}$
ZMC-2 1929 16.920
MACON 1933 1.958
ZPG-2 1954 11.594
TANKER B
742-321S
742-321S NUC
C4-ST-67a
C4-S-1a
C3-ST-14a
742-320S
C4-S-57a
TANKER A
742-320S NUC
TANKER C
VC2-S-AP3
C3-S-A2
C1A
C2-S-AJ1
C1-M-AV1
T2-SE-A1
MED. TANKER
S. S. MANHATTAN

Fig. 40



P L X V_CRU / WORK INPUT
YEAR ENTER SERVICE
100
80
60
40
30
20
10
8
6
4
3
2
1
.8
.6
.4
.3
.2
.1
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
Y.E.S.
P/L X V_CRU / WORK INPUT
ZMC-2 1929 .275
MACON 1933 2.385
S. S. MANHATTAN
T2-SE-A1
C1-M-AV1
MED. TANKER
C1A
C2-S-AJ1
C3-S-A2
VC2-S-AP3
C4-S-1a
C3-ST-14a
C4-S-57a
C4-ST-67a
742-320S
742-321S
742-303
742-302
742-310
742-304
742-309
742-305, -306
742-311
742-307, -308
CL-44D-4
C-135B
707-320C
748 B-15
JRM-2
C-118A
C-124C
C-133A
C-130E
L-300
742-322S
90 TON P/L GEM
ZPG-2
VERTOL HC-1B
15 TON P/L GEM

Fig. 41

3.2.3 DATA PLOTTED vs P/L x V_{cru}

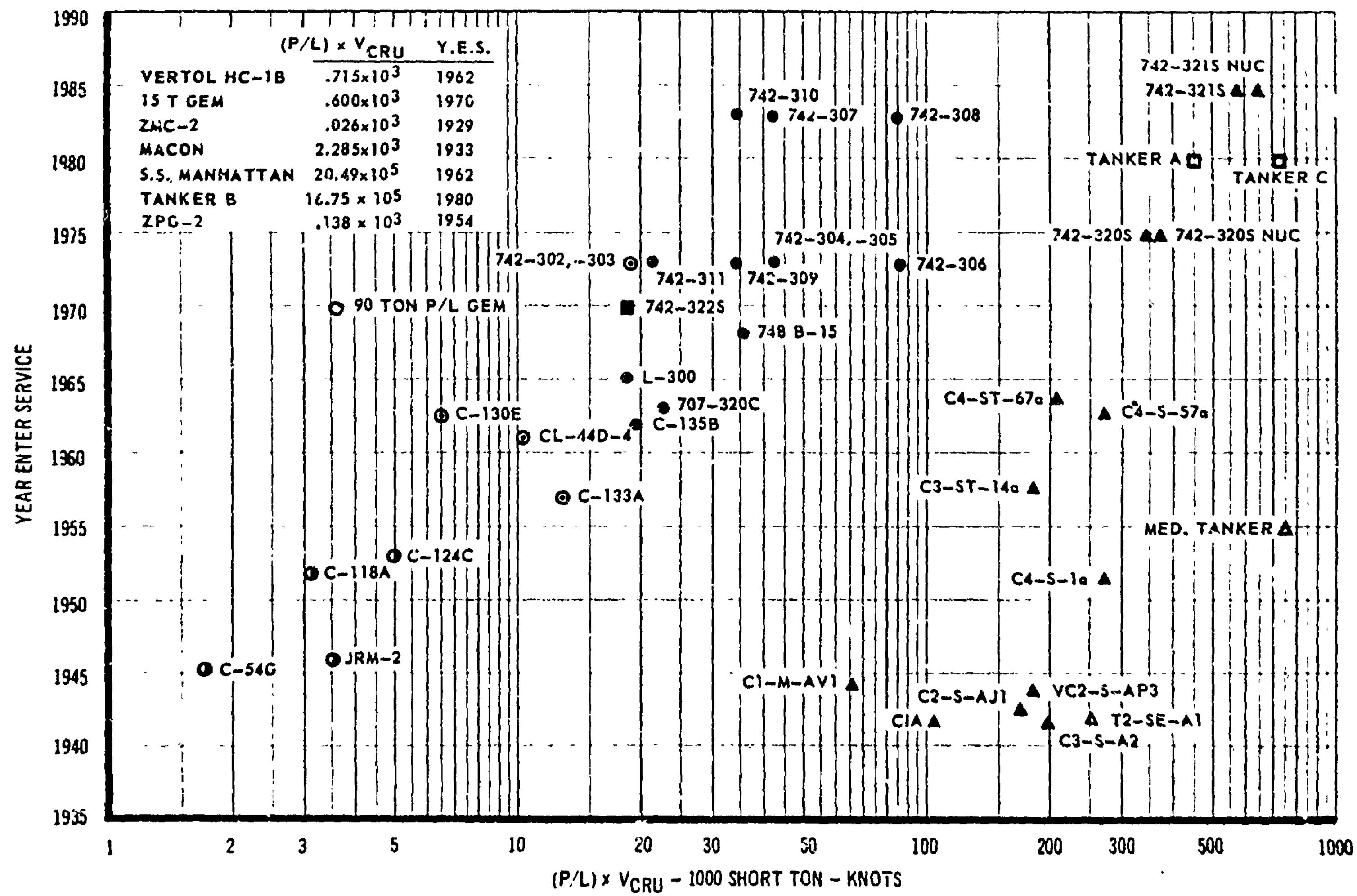
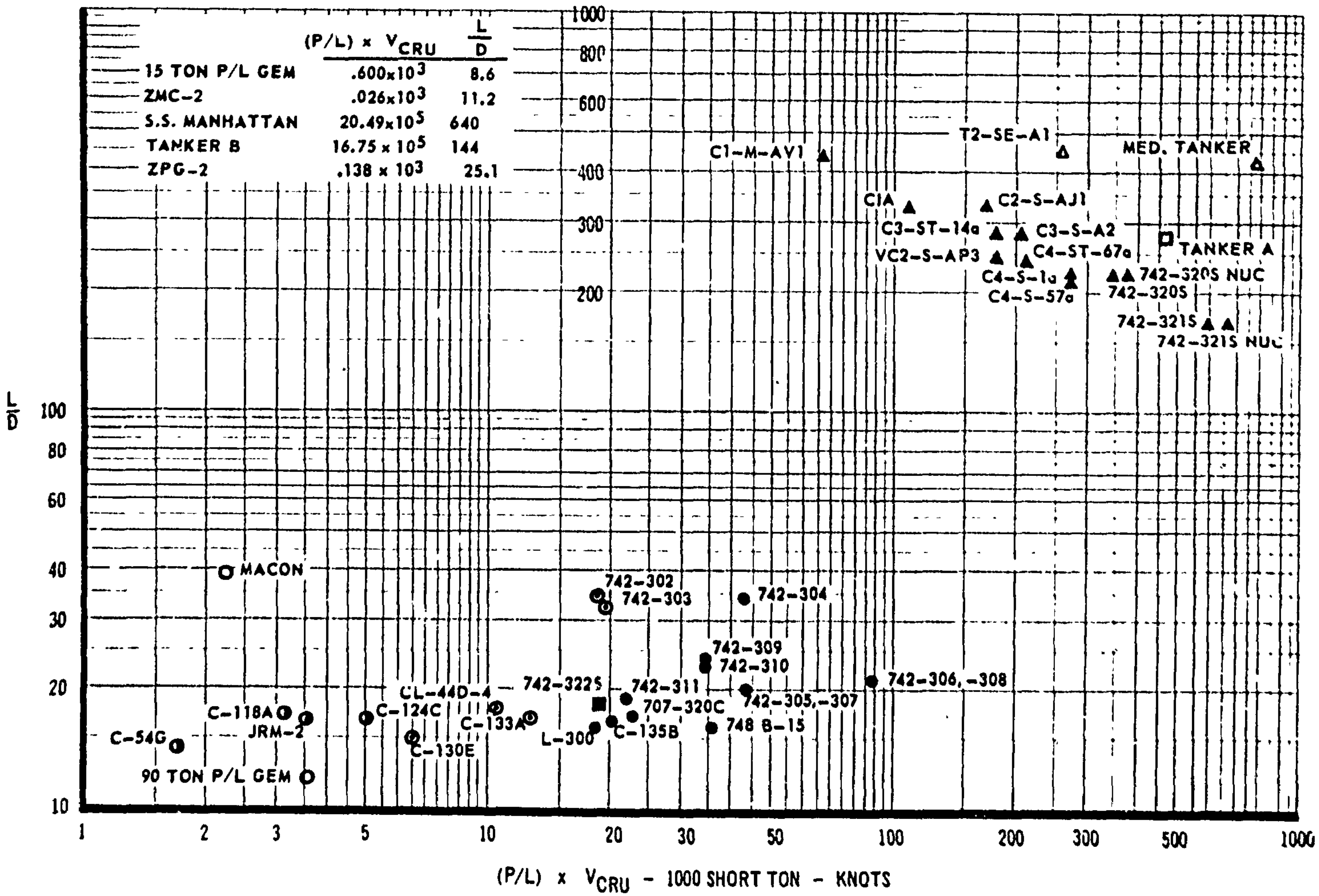
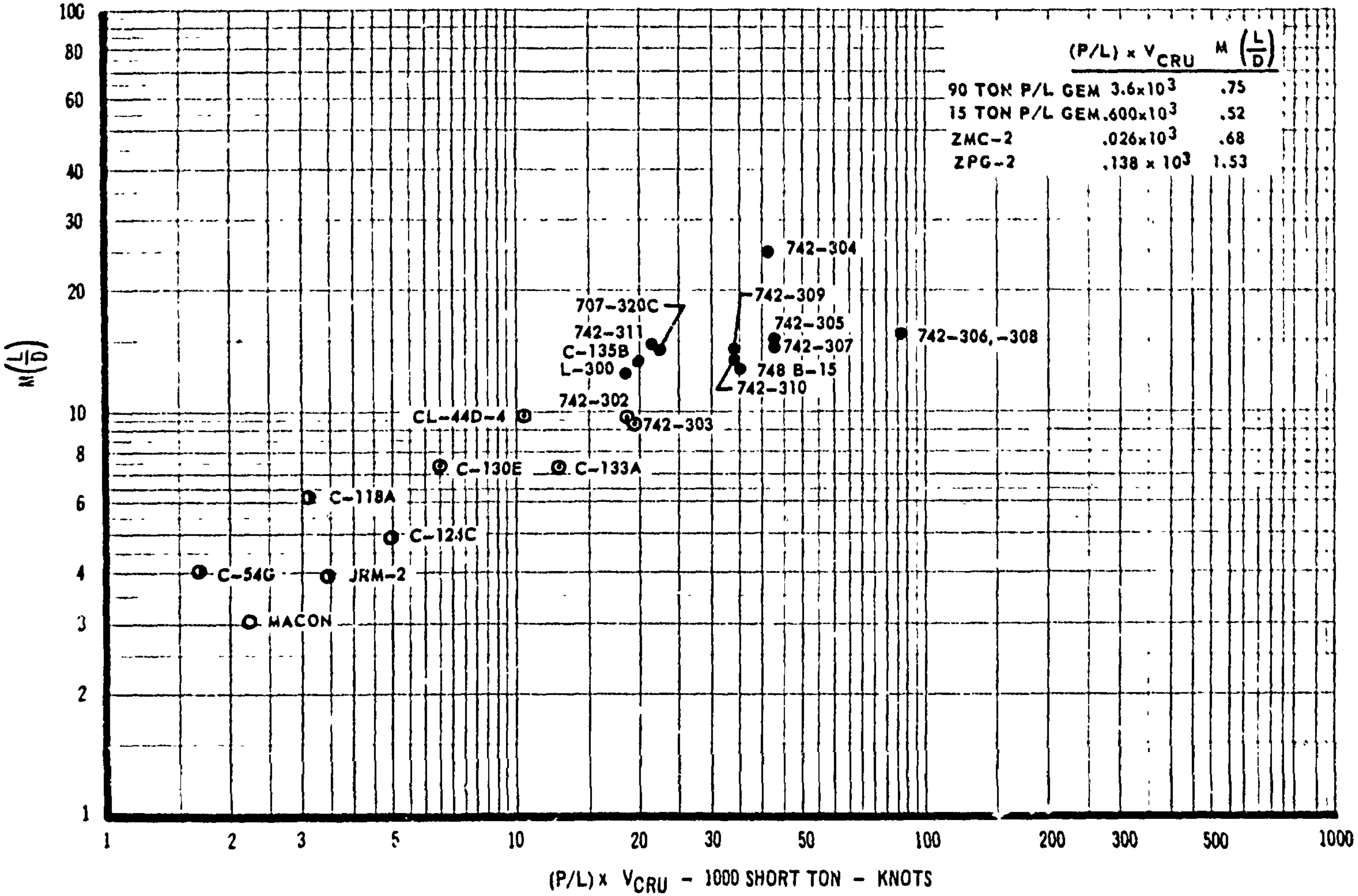

(P/L) x V_CRU
Y.E.S.
VERTOL HC-1B .715x10^3 1962
15 T GEM .600x10^3 1970
ZMC-2 .026x10^3 1929
MACON 2.285x10^3 1933
S.S. MANHATTAN 20.49x10^5 1962
TANKER B 16.75 x 10^5 1980
ZPG-2 .138 x 10^3 1954
742-321S NUC
742-321S
742-310
742-307
742-308
TANKER A
TANKER C
742-320S
742-320S NUC
742-304, -305
742-302, -303
742-311
742-309
742-306
90 TON P/L GEM
742-322S
748 B-15
L-300
707-320C
C-135B
C-130E
CL-44D-4
C4-ST-67a
C4-S-57a
C-133A
C3-ST-14a
MED. TANKER
C-124C
C-118A
C4-S-1a
C-54G
JRM-2
C1-M-AV1
C2-S-AJ1
VC2-S-AP3
CIA
T2-SE-A1
C3-S-A2
YEAR ENTER SERVICE
1990
1985
1980
1975
1970
1965
1960
1955
1950
1945
1940
1935
1
2
3
5
10
20
30
50
100
200
300
500
1000
(P/L) x V_CRU - 1000 SHORT TON - KNOTS

Fig. 42



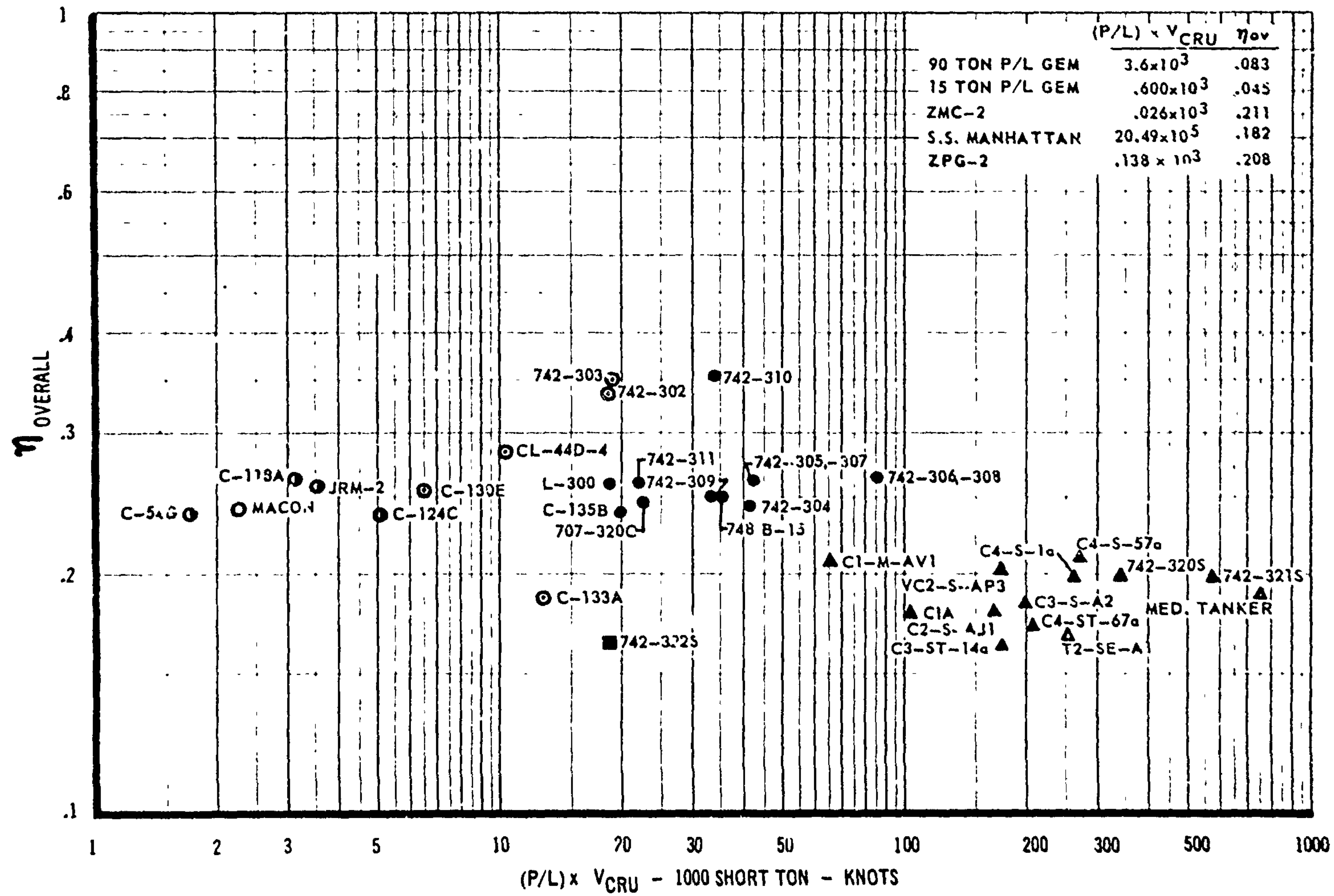
(P/L) x V_{CRU}
L/D
15 TON P/L GEM .600x10^3 8.6
ZMC-2 .026x10^3 11.2
S.S. MANHATTAN 20.49x10^5 640
TANKER B 16.75 x 10^5 144
ZPG-2 .138 x 10^3 25.1
C1-M-AV1
T2-SE-A1
MED. TANKER
C1A
C2-S-AJ1
C3-ST-14a
C3-S-A2
VC2-S-AP3
C4-ST-67a
TANKER A
C4-S-1a
C4-S-57a
742-320S NUC
742-320S
742-321S
742-321S NUC
MACON
742-302
742-303
742-304
742-309
742-310
742-306, -308
742-322S
742-311
707-320C
742-305, -307
CL-44D-4
C-124C
C-133A
L-300
C-135B
748 B-15
C-118A
JRM-2
C-54G
C-130E
90 TON P/L GEM
L/D
(P/L) x V_{CRU} - 1000 SHORT TON - KNOTS

Fig. 43



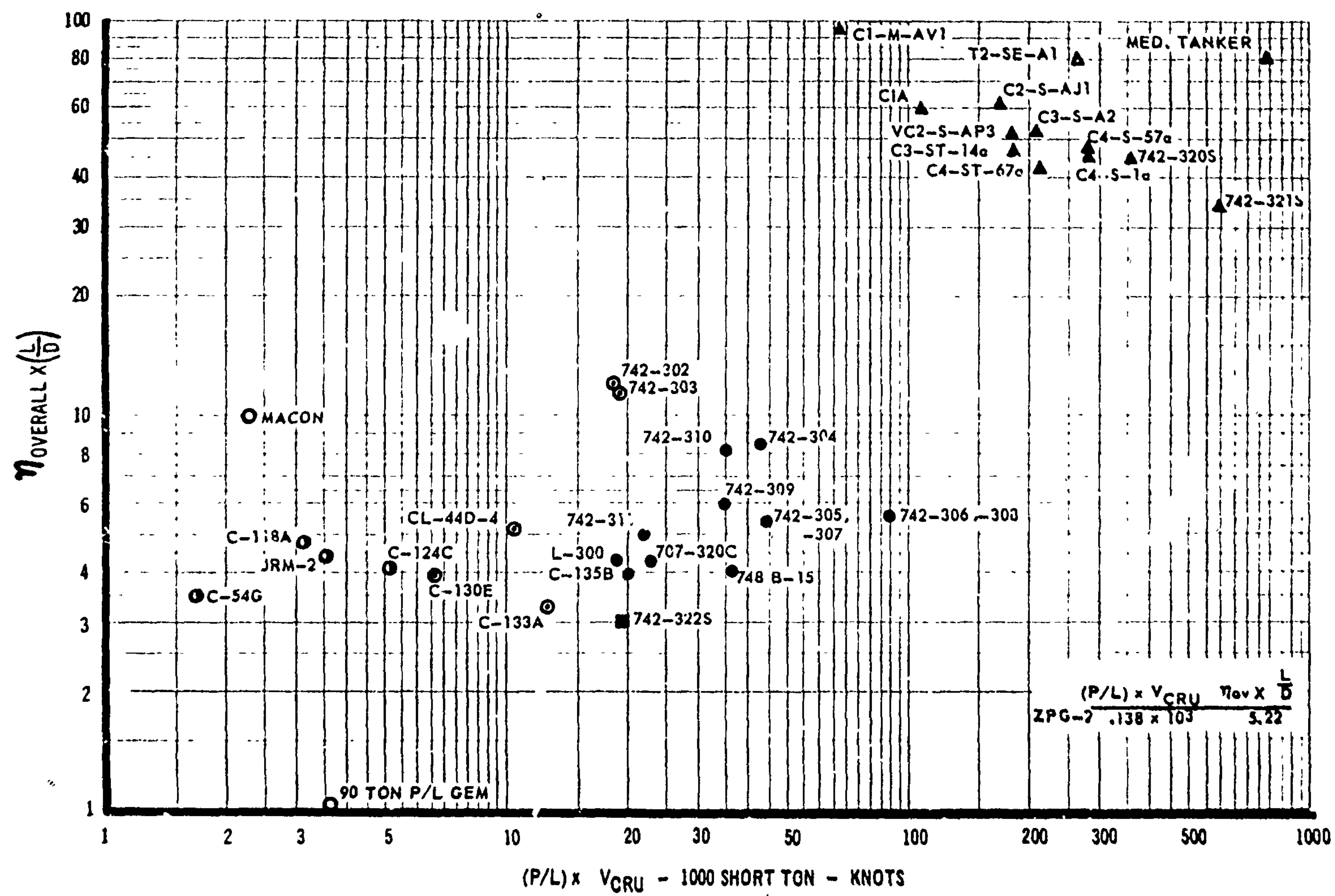
(P/L) x VCRU
M (L/D)
90 TON P/L GEM 3.6x10^3 .75
15 TON P/L GEM .600x10^3 .52
ZMC-2 .026x10^3 .68
ZPG-2 .138 x 10^3 1.53
742-304
742-309
707-320C
742-305
742-311
742-307
742-306, -308
C-135B
748 B-15
L-300
742-310
742-302
CL-44D-4
742-303
C-130E
C-133A
C-118A
C-124C
C-54G
JRM-2
MACON
M(L/D)
(P/L) x VCRU - 1000 SHORT TON - KNOTS

Fig. 44



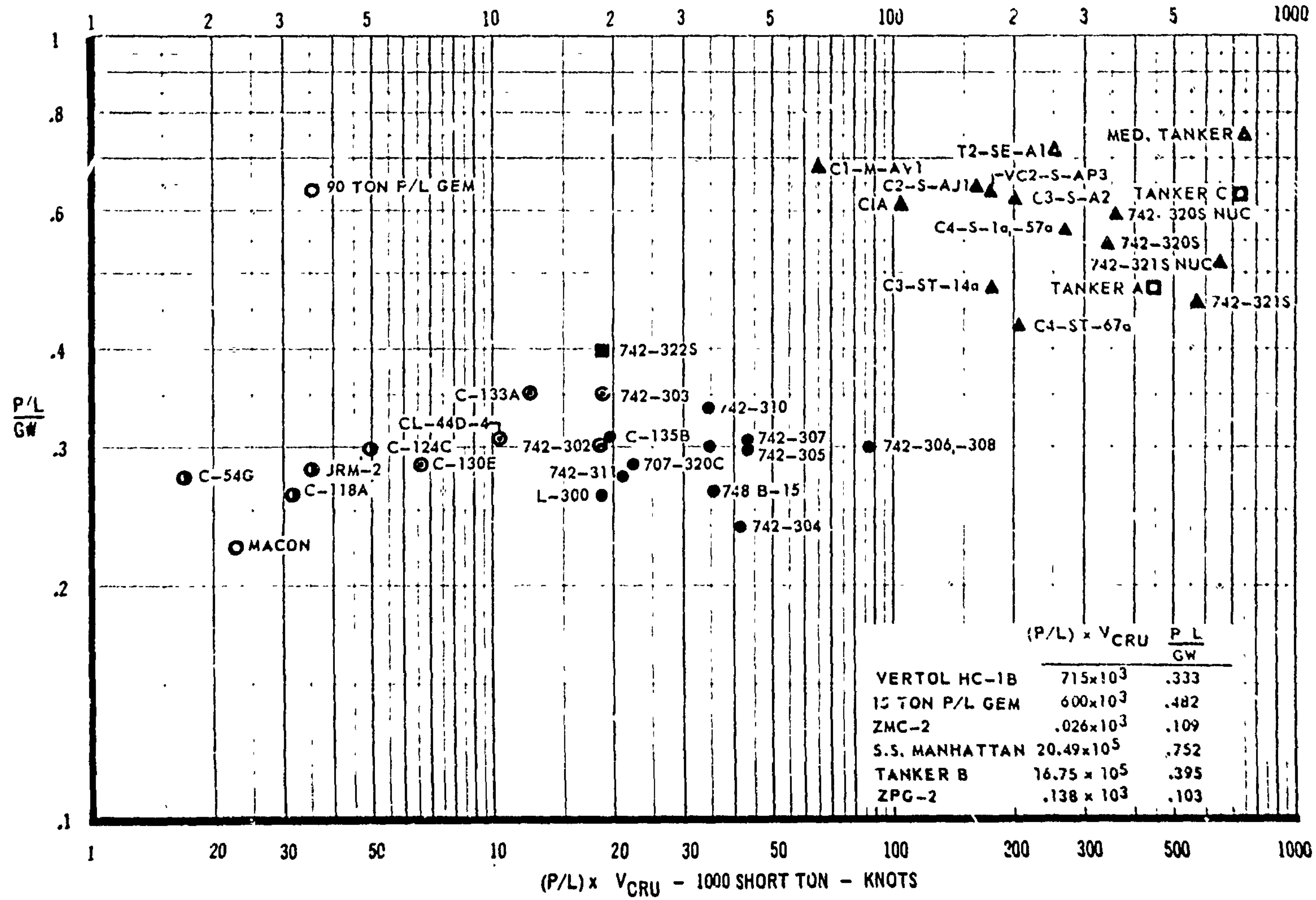
(P/L) × V_{CRU}
η_{ov}
90 TON P/L GEM
3.6x10^3
.083
15 TON P/L GEM
.600x10^3
.045
ZMC-2
.026x10^3
.211
S.S. MANHATTAN
20.49x10^5
.182
ZPG-2
.138 x 10^3
.208
$\eta_{OVERALL}$
(P/L) x V_{CRU} - 1000 SHORT TON - KNOTS
C-118A
JRM-2
MACON
C-130E
C-124C
CL-44D-4
742-303
742-302
742-310
742-311
742-309
L-300
C-135B
707-320C
742-305,-307
742-306-308
742-304
748 B-13
C-133A
742-322S
C1-M-AV1
C4-S-1a
C4-S-57a
742-320S
742-321S
VC2-S-AP3
C3-S-A2
C1A
C2-S-AJ1
C4-ST-67a
MED. TANKER
C3-ST-14a
T2-SE-A1

Fig. 45



C1-M-AV1
T2-SE-A1
MED. TANKER
C1A
C2-S-AJ1
C3-S-A2
VC2-S-AP3
C3-ST-14a
C4-ST-67a
C4-S-57a
742-320S
C4-S-1a
742-321S
742-302
742-303
MACON
742-310
742-304
742-309
742-305, -307
742-306, -303
CL-44D-4
C-118A
JRM-2
C-124C
C-130E
C-54G
742-31
L-300
C-135B
707-320C
748 B-15
C-133A
742-322S
90 TON P/L GEM
$ZPG-2 \quad \frac{(P/L) \times V_{CRU}}{.138 \times 10^3} \quad \frac{\eta_{ov} \times \frac{L}{D}}{5.22}$
$\eta_{OVERALL} \times \left(\frac{L}{D}\right)$
$(P/L) \times V_{CRU}$ - 1000 SHORT TON - KNOTS

Fig. 46



	$(P/L) \times V_{CRU}$	$\frac{P/L}{GW}$
VERTOL HC-1B	715×10^3	.333
15 TON P/L GEM	600×10^3	.482
ZMC-2	$.026\times10^3$	.109
S.S. MANHATTAN	20.49×10^5	.752
TANKER B	16.75×10^5	.395
ZPG-2	$.138\times10^3$	.103

Fig. 47

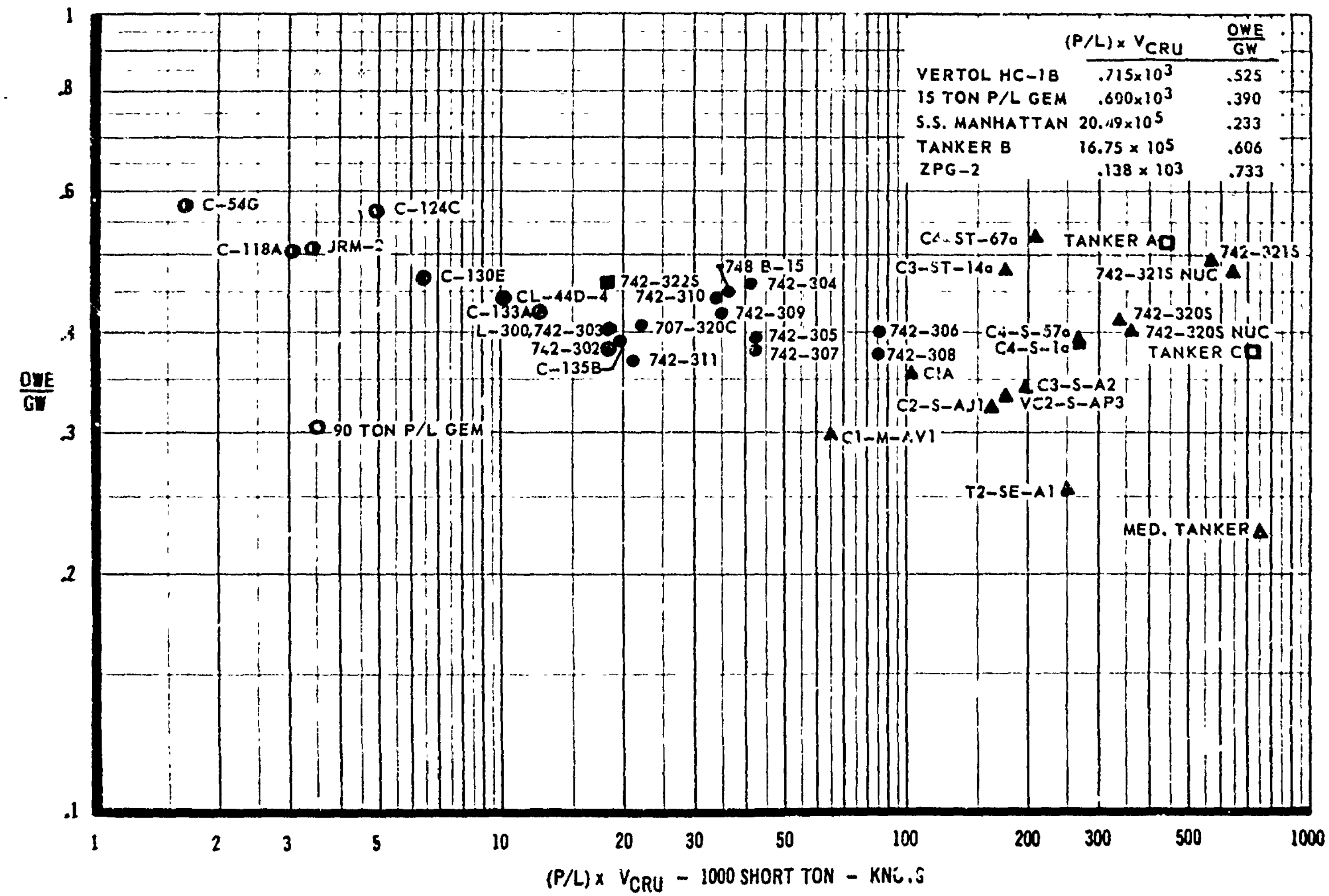

(P/L) x V_{CRU}
OWE/GW
VERTOL HC-1B .715x10^3 .525
15 TON P/L GEM .690x10^3 .390
S.S. MANHATTAN 20.49x10^5 .233
TANKER B 16.75 x 10^5 .606
ZPG-2 .138 x 10^3 .733
C-54G
C-124C
C-118A
JRM-2
C-130E
CL-44D-4
C-133A
L-300,742-303
742-302
C-135B
742-322S
742-310
707-320C
742-311
748 B-15
742-304
742-309
742-305
742-307
90 TON P/L GEM
C1-M-AV1
742-306
742-308
C1A
C2-S-AJ1
C3-S-A2
VC2-S-AP3
C4-ST-67a
C3-ST-14a
C4-S-57a
C4-S-1a
T2-SE-A1
TANKER A
742-321S
742-321S NUC
742-320S
742-320S NUC
TANKER C
MED. TANKER
OWE/GW
1
.8
.6
.4
.3
.2
.1
1
2
3
5
10
20
30
50
100
200
300
500
1000
(P/L) x V_{CRU} - 1000 SHORT TON - KNOTS

Fig. 48

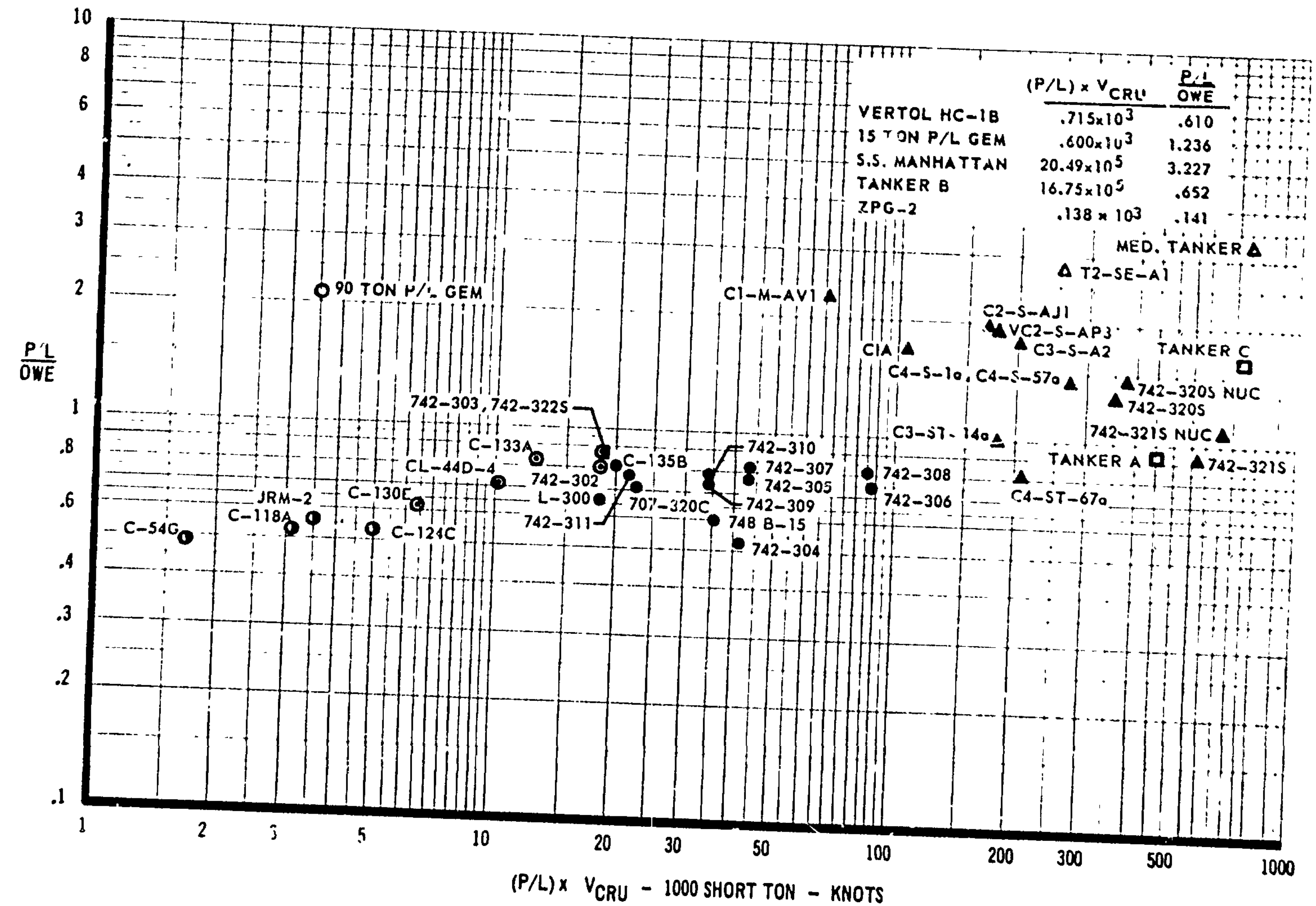
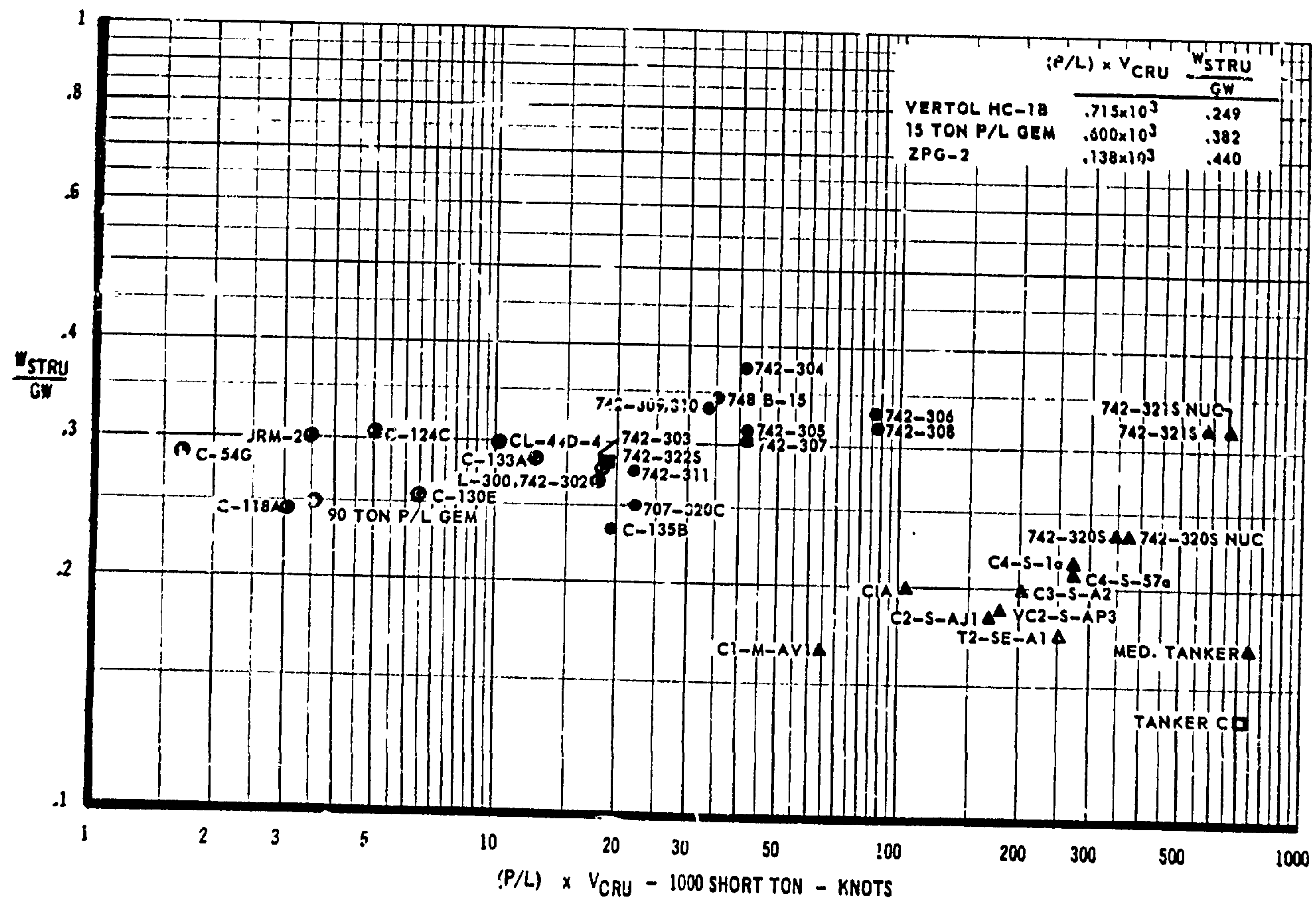
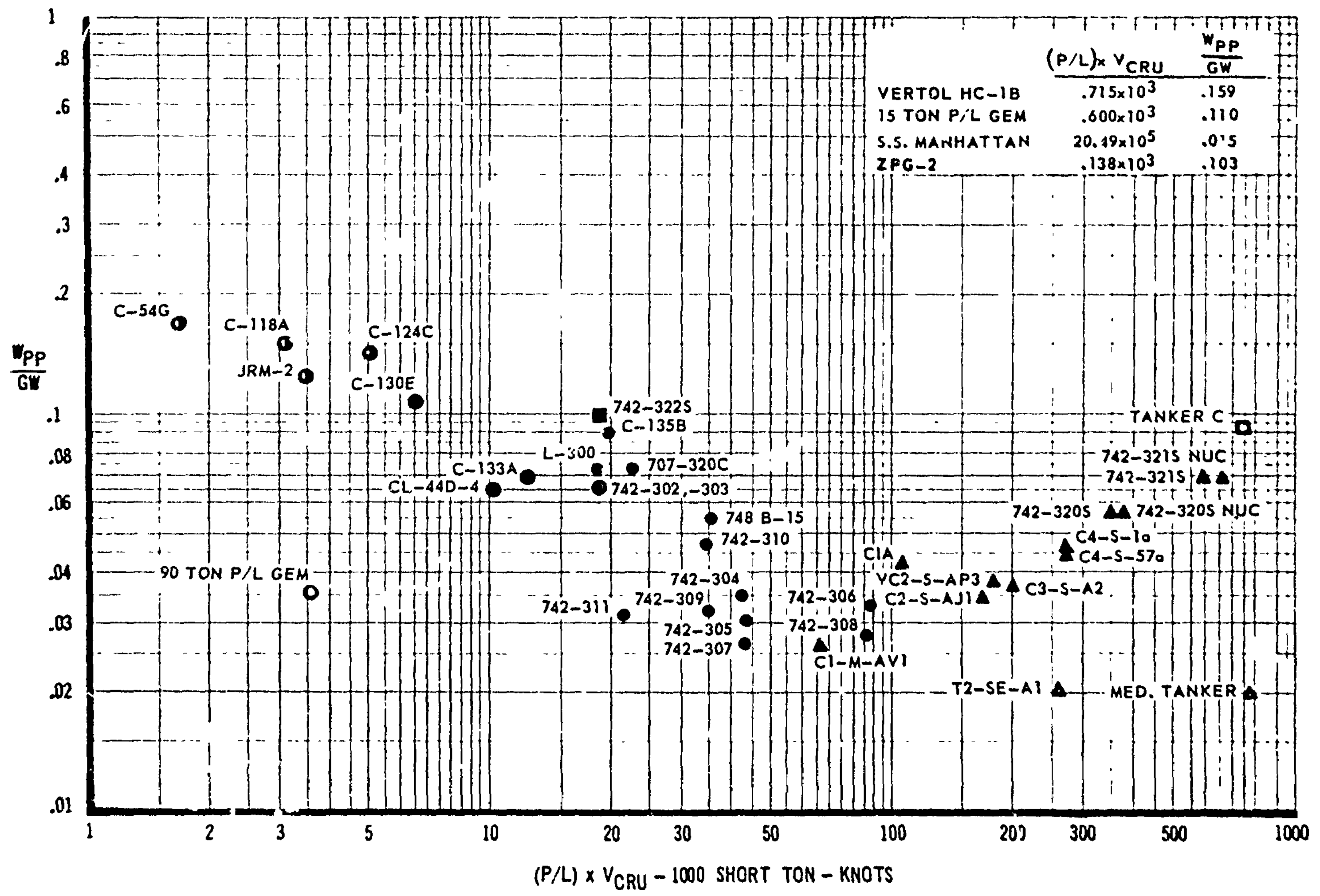

(P/L) x V_{CRU}
P/L / OWE
VERTOL HC-1B .715x10^3 .610
15 TON P/L GEM .600x10^3 1.236
S.S. MANHATTAN 20.49x10^5 3.227
TANKER B 16.75x10^5 .652
ZPG-2 .138 x 10^3 .141
MED. TANKER
T2-SE-A1
90 TON P/L GEM
C1-M-AV1
C2-S-AJ1
VC2-S-AP3
C3-S-A2
TANKER C
CIA
C4-S-1a, C4-S-57a
742-320S NUC
742-320S
742-303, 742-322S
C3-ST-14a
742-321S NUC
C-133A
742-310
TANKER A
742-321S
CL-44D-4
C-135B
742-307
742-308
742-305
742-302
742-306
C-130E
L-300
707-320C
742-309
C4-ST-67a
JRM-2
742-311
748 B-15
C-118A
C-54G
C-124C
742-304
P/L / OWE
(P/L) x V_{CRU} - 1000 SHORT TON - KNOTS

Fig. 49



(P/L) x VCRU | WSTRU/GW
VERTOL HC-1B .715x10^3 .249
15 TON P/L GEM .600x10^3 .382
ZPG-2 .138x10^3 .440
C-54G
JRM-2
C-118A
90 TON P/L GEM
C-124C
C-130E
CL-44D-4
C-133A
L-300,742-302
742-303
742-322S
742-311
707-320C
C-135B
742-309,310
748 B-15
742-304
742-305
742-307
742-306
742-308
C1-M-AV1
C1A
C2-S-AJ1
YC2-S-AP3
T2-SE-A1
C3-S-A2
C4-S-1a
C4-S-57a
742-320S
742-320S NUC
742-321S NUC
742-321S
MED. TANKER
TANKER C
WSTRU/GW
(P/L) x VCRU - 1000 SHORT TON - KNOTS

Fig. 50



$\frac{W_{PP}}{GW}$
(P/L) x V_{CRU} – 1000 SHORT TON – KNOTS
$(P/L) \times V_{CRU}$ | $\frac{W_{PP}}{GW}$
VERTOL HC-1B .715x10³ .159
15 TON P/L GEM .600x10³ .110
S.S. MANHATTAN 20.49x10⁵ .0'5
ZPG-2 .138x10³ .103
C-54G
C-118A
JRM-2
C-124C
C-130E
742-322S
C-135B
L-300
707-320C
C-133A
CL-44D-4
742-302,-303
748 B-15
742-310
90 TON P/L GEM
742-304
742-309
742-311
742-305
742-307
742-306
742-308
C1-M-AV1
C1A
VC2-S-AP3
C2-S-AJ1
C3-S-A2
C4-S-1a
C4-S-57a
742-320S
742-320S NUC
742-321S
742-321S NUC
TANKER C
T2-SE-A1
MED. TANKER

Fig. 51

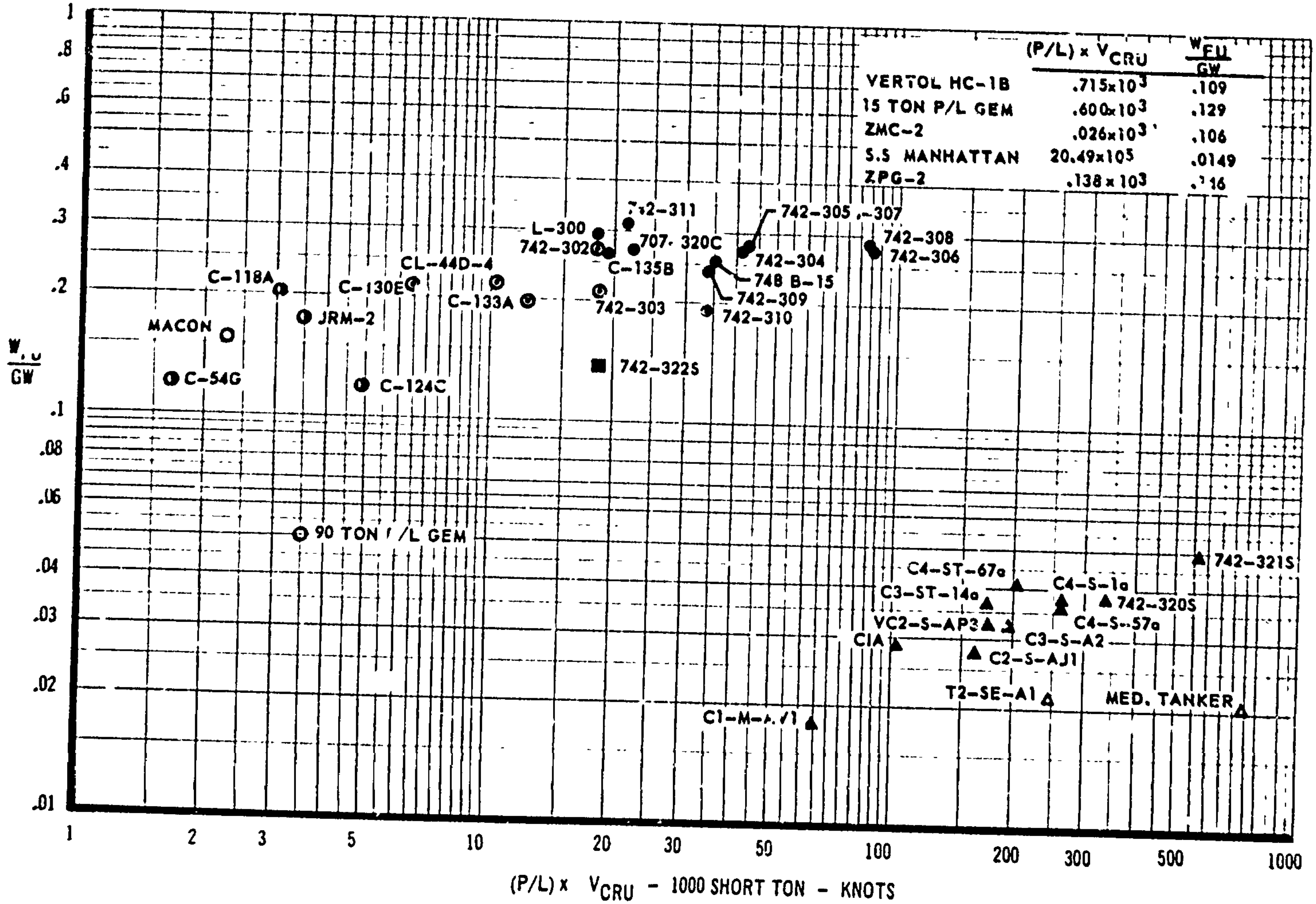
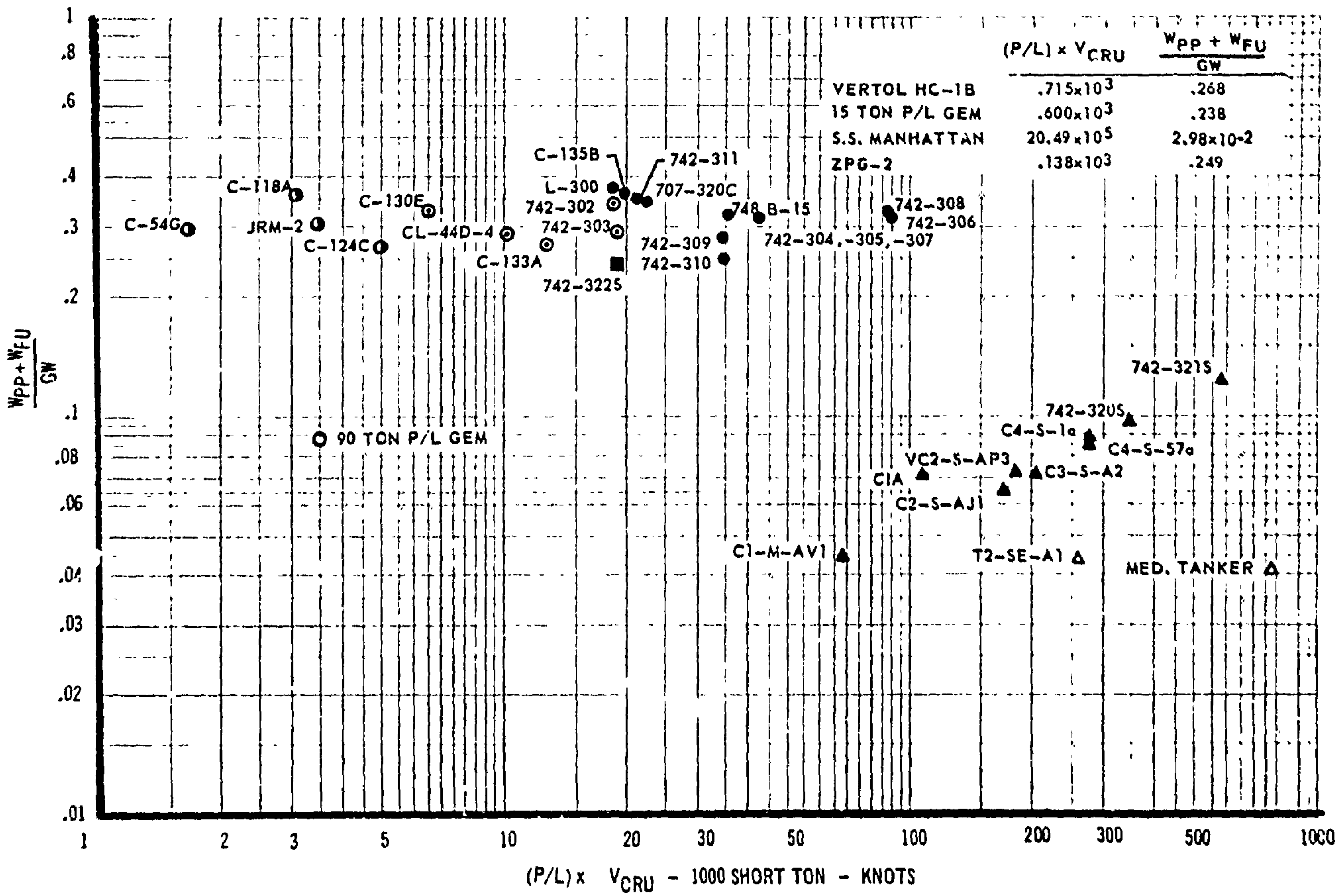
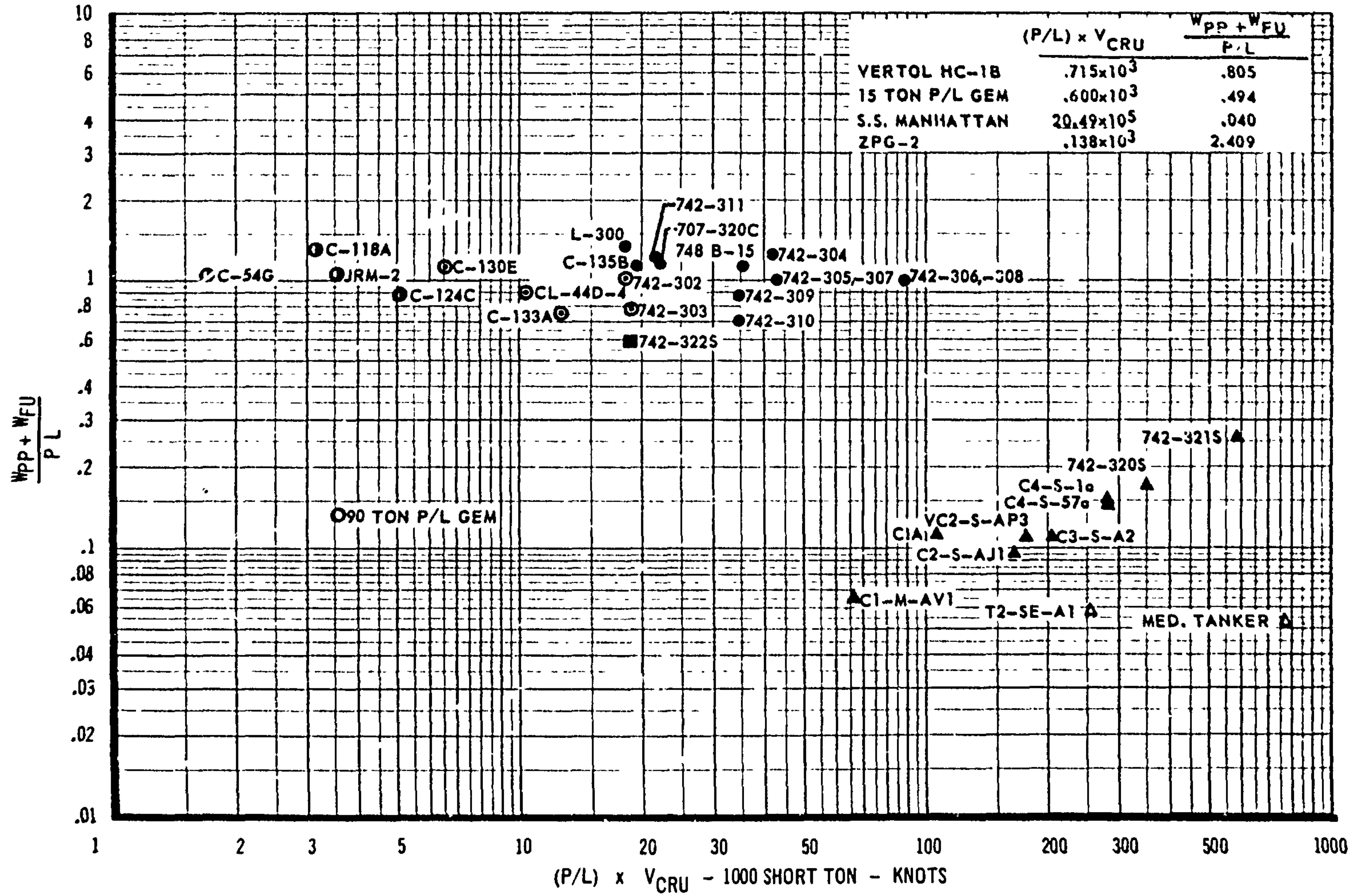

(P/L) x V_{CRU}
$\frac{W_{FU}}{GW}$
VERTOL HC-1B .715x10^3 .109
15 TON P/L GEM .600x10^3 .129
ZMC-2 .026x10^3 .106
S.S MANHATTAN 20.49x10^5 .0149
ZPG-2 .138 x 10^3
C-118A
MACON
C-54G
JRM-2
C-130E
C-124C
CL-44D-4
C-133A
90 TON
L-300
742-302
742-303
742-322S
C-135B
707. 320C
742-304
748 B-15
742-309
742-310
742-305 ,-307
742-308
742-306
C4-ST-67a
C3-ST-14a
VC2-S-AP3
CIA
C3-S-A2
C2-S-AJ1
C4-S-1a
742-320S
C4-S-57a
742-321S
T2-SE-A1
MED. TANKER
$\frac{W_{FU}}{GW}$
(P/L) x V_{CRU} - 1000 SHORT TON - KNOTS

Fig. 52



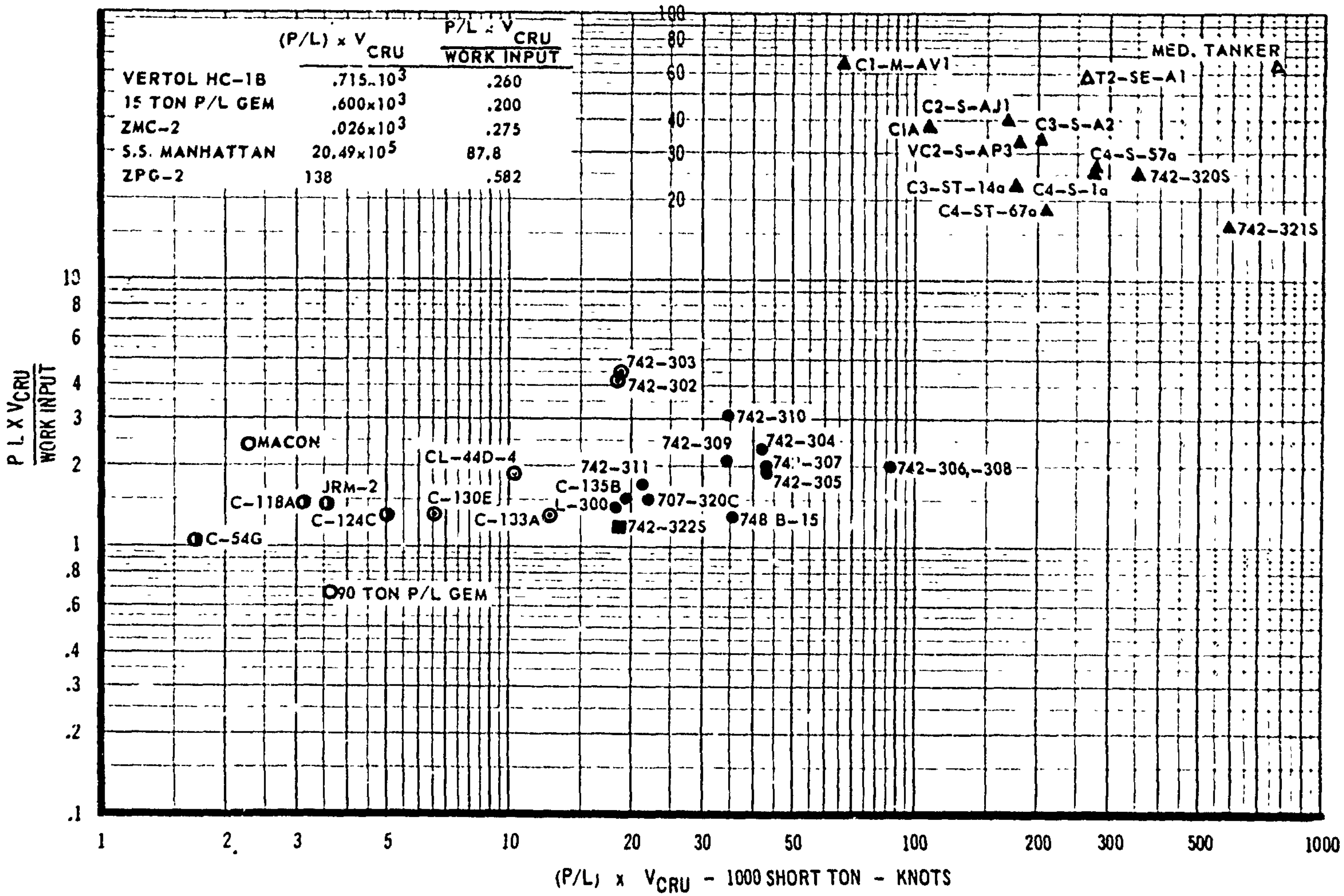
(P/L) x V_CRU
(W_PP + W_FU)/GW
VERTOL HC-1B .715x10^3 .268
15 TON P/L GEM .600x10^3 .238
S.S. MANHATTAN 20.49x10^5 2.98x10-2
ZPG-2 .138x10^3 .249
C-54G
C-118A
JRM-2
C-124C
C-130E
CL-44D-4
C-133A
C-135B
L-300
742-302
742-303
742-311
707-320C
742-322S
742-309
742-310
748 B-15
742-304,-305,-307
742-308
742-306
90 TON P/L GEM
C1-M-AV1
C1A
VC2-S-AP3
C2-S-AJ1
C3-S-A2
C4-S-1a
C4-S-57a
742-320S
742-321S
T2-SE-A1
MED. TANKER
W_PP+W_FU / GW
(P/L) x V_CRU - 1000 SHORT TON - KNOTS

Fig. 53



(P/L) x V_{CRU}
$\frac{W_{PP} + W_{FU}}{P/L}$
VERTOL HC-1B .715x10^3 .805
15 TON P/L GEM .600x10^3 .494
S.S. MANHATTAN 20.49x10^5 .040
ZPG-2 .138x10^3 2.409
C-54G
C-118A
JRM-2
C-124C
C-130E
CL-44D-4
C-133A
L-300
C-135B
742-311
707-320C
748 B-15
742-302
742-303
742-322S
742-304
742-305,-307
742-306,-308
742-309
742-310
90 TON P/L GEM
742-321S
742-320S
C4-S-1a
C4-S-57a
VC2-S-AP3
C1A
C3-S-A2
C2-S-AJ1
C1-M-AV1
T2-SE-A1
MED. TANKER
10 8 6 4 3 2 1 .8 .6 .4 .3 .2 .1 .08 .06 .04 .03 .02 .01
1 2 3 5 10 20 30 50 100 200 300 500 1000
$\frac{W_{PP} + W_{FU}}{P\ L}$
(P/L) x V_{CRU} - 1000 SHORT TON - KNOTS

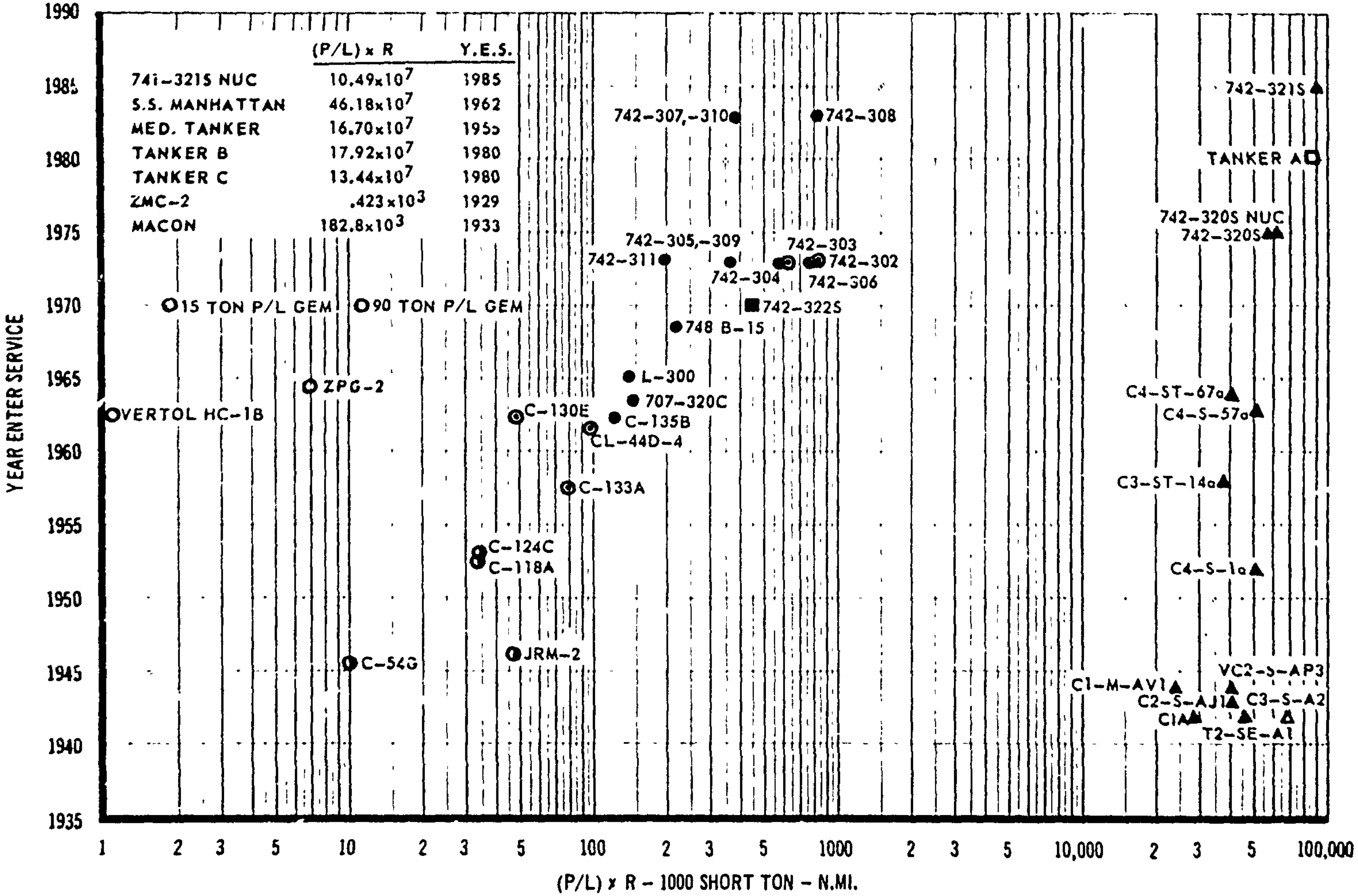
Fig. 54



(P/L) x VCRU
P/L x VCRU / WORK INPUT
VERTOL HC-1B .715x10^3 .260
15 TON P/L GEM .600x10^3 .200
ZMC-2 .026x10^3 .275
S.S. MANHATTAN 20.49x10^5 87.8
ZPG-2 138 .582
MED. TANKER
C1-M-AV1
T2-SE-A1
C2-S-AJ1
C1A
C3-S-A2
VC2-S-AP3
C4-S-57a
742-320S
C3-ST-14a
C4-S-1a
C4-ST-67a
742-321S
742-303
742-302
742-310
742-309
742-304
742-307
742-305
742-306, -308
OMACON
CL-44D-4
742-311
C-135B
JRM-2
C-130E
L-300
707-320C
C-118A
C-124C
C-133A
742-322S
748 B-15
C-54G
90 TON P/L GEM
P L X VCRU / WORK INPUT
(P/L) x VCRU - 1000 SHORT TON - KNOTS

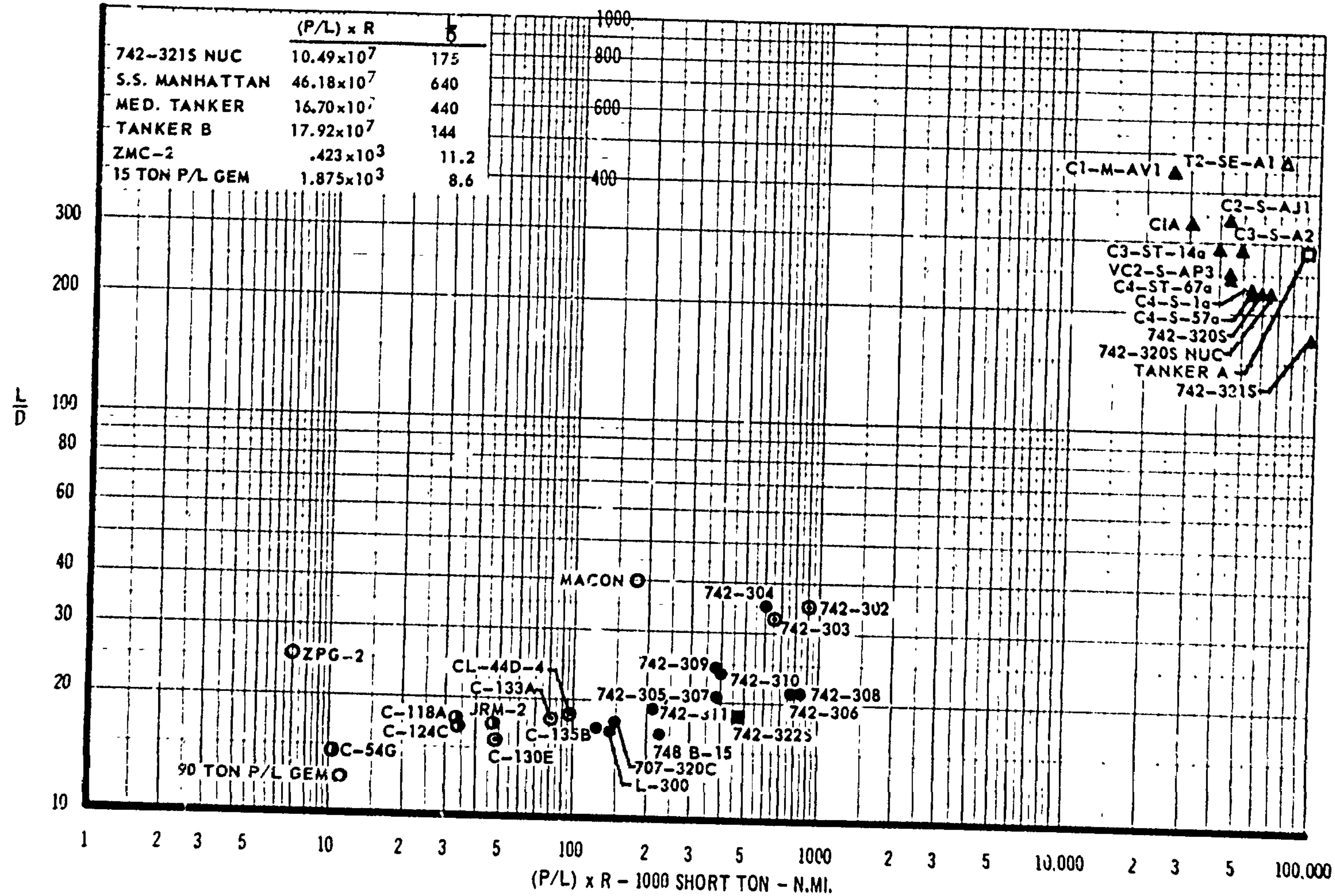
Fig. 55

3.2.4 DATA PLOTTED vs $P/L \times R$



(P/L) x R
Y.E.S.
74i-321S NUC 10.49x10^7 1985
S.S. MANHATTAN 46.18x10^7 1962
MED. TANKER 16.70x10^7 1955
TANKER B 17.92x10^7 1980
TANKER C 13.44x10^7 1980
ZMC-2 .423x10^3 1929
MACON 182.8x10^3 1933
742-307,-310
742-308
742-321S
TANKER A
742-320S NUC
742-320S
742-305,-309
742-311
742-304
742-303
742-302
742-306
742-322S
748 B-15
15 TON P/L GEM
90 TON P/L GEM
L-300
707-320C
C-135B
CL-44D-4
C-130E
ZPG-2
VERTOL HC-1B
C-133A
C-124C
C-118A
JRM-2
C-54G
C4-ST-67a
C4-S-57a
C3-ST-14a
C4-S-1a
C1-M-AV1
VC2-S-AP3
C2-S-AJ1
C3-S-A2
C1A
T2-SE-A1
YEAR ENTER SERVICE
1990
1985
1980
1975
1970
1965
1960
1955
1950
1945
1940
1935
1 2 3 5 10 2 3 5 100 2 3 5 1000 2 3 5 10,000 2 3 5 100,000
(P/L) x R – 1000 SHORT TON – N.MI.

Fig. 56



(P/L) x R
L/D
742-321S NUC 10.49x10^7 175
S.S. MANHATTAN 46.18x10^7 640
MED. TANKER 16.70x10^7 440
TANKER B 17.92x10^7 144
ZMC-2 .423x10^3 11.2
15 TON P/L GEM 1.875x10^3 8.6
C1-M-AV1
T2-SE-A1
C2-S-AJ1
CIA
C3-S-A2
C3-ST-14a
VC2-S-AP3
C4-ST-67a
C4-S-1a
C4-S-57a
742-320S
742-320S NUC
TANKER A
742-321S
MACON
742-304
742-302
742-303
742-309
742-310
742-305, 742-307
742-308
742-306
742-311
742-322S
748 B-15
707-320C
L-300
ZPG-2
CL-44D-4
C-133A
JRM-2
C-118A
C-124C
C-135B
C-130E
C-54G
90 TON P/L GEM
(P/L) x R – 1000 SHORT TON – N.MI.

Fig. 57

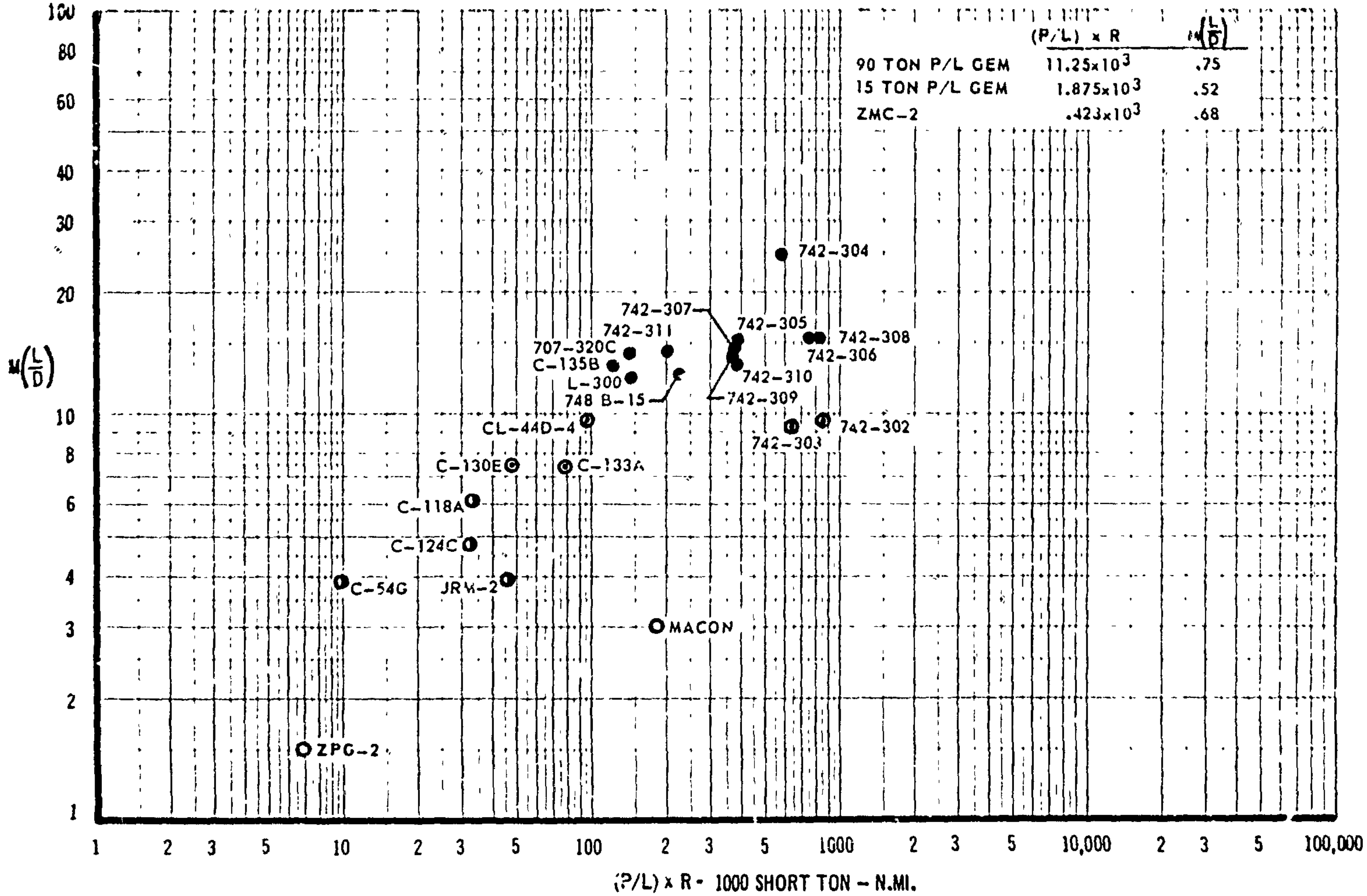
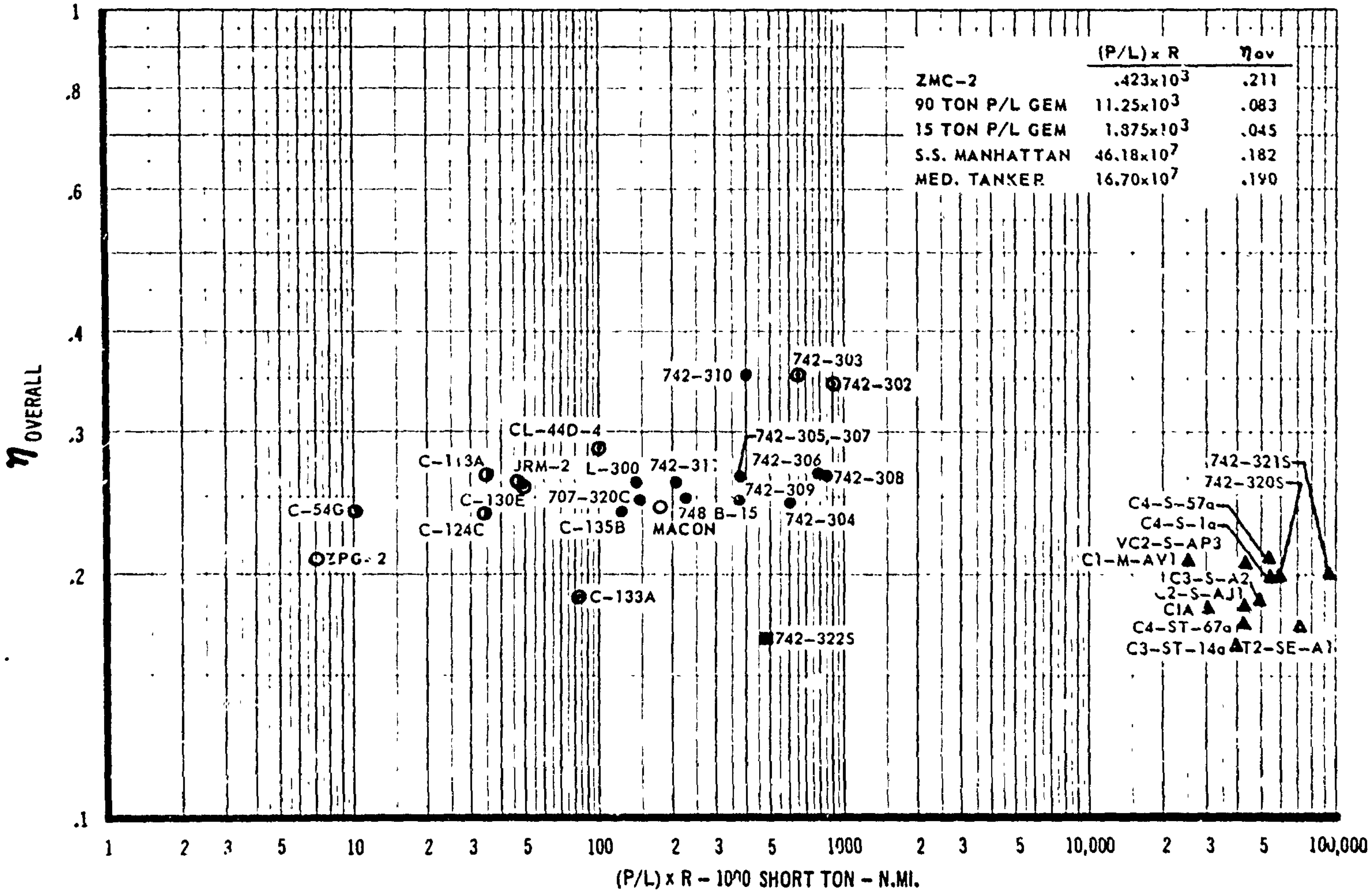
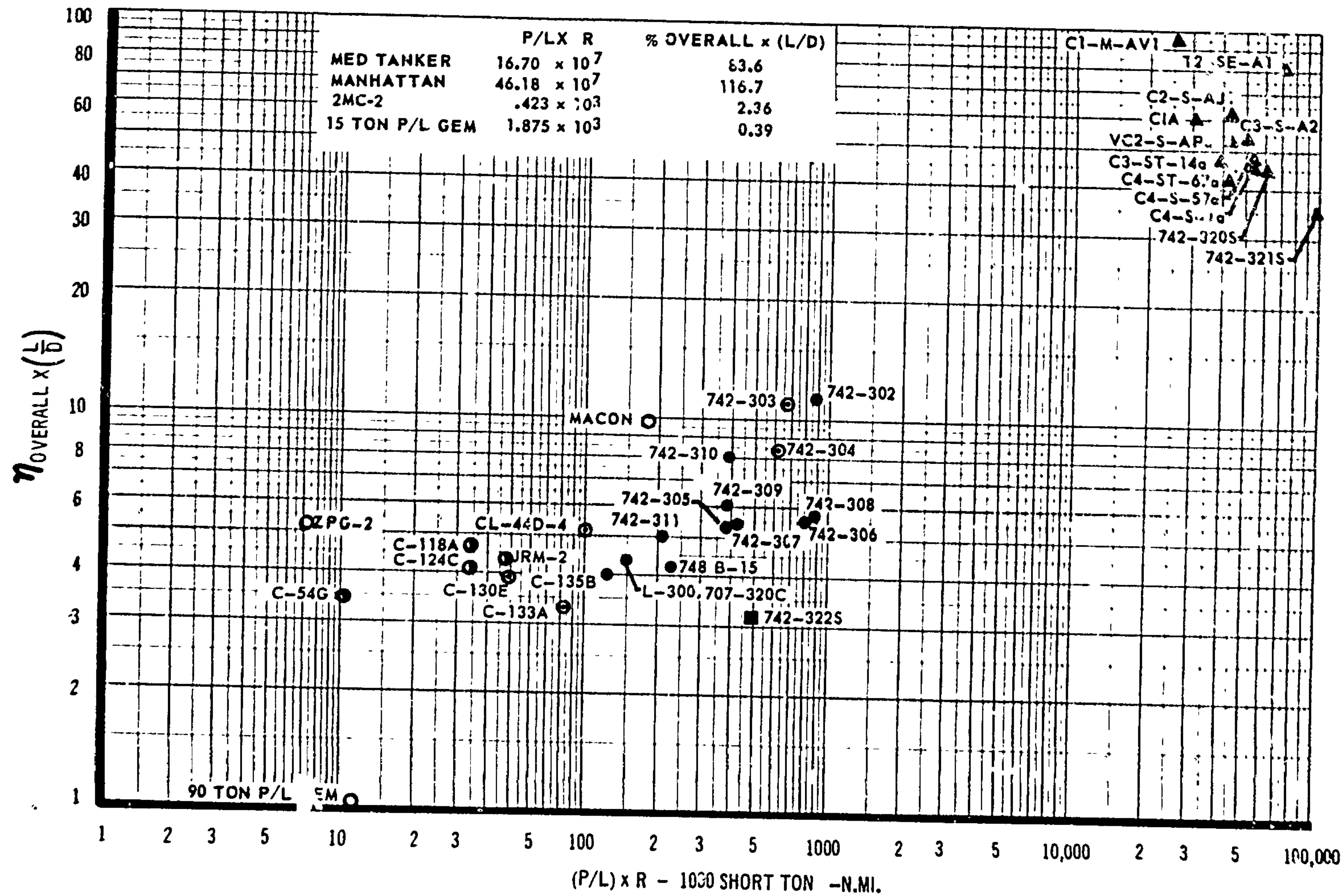

(P/L) x R
M(L/D)
90 TON P/L GEM 11.25x10^3 .75
15 TON P/L GEM 1.875x10^3 .52
ZMC-2 .423x10^3 .68
742-304
742-307
742-305
742-308
742-306
742-311
707-320C
C-135B
L-300
748 B-15
742-310
742-309
CL-44D-4
742-302
742-303
C-130E
C-133A
C-118A
C-124C
C-54G
JRM-2
MACON
ZPG-2
M(L/D)
(P/L) x R - 1000 SHORT TON - N.MI.

Fig. 58



$\eta_{OVERALL}$
(P/L) x R – 1000 SHORT TON – N.MI.
(P/L) x R
η_{ov}
ZMC-2
.423x10^3
.211
90 TON P/L GEM
11.25x10^3
.083
15 TON P/L GEM
1.875x10^3
.045
S.S. MANHATTAN
46.18x10^7
.182
MED. TANKER
16.70x10^7
.190
C-54G
ZPG-2
C-113A
C-130E
C-124C
JRM-2
CL-44D-4
L-300
707-320C
C-135B
C-133A
MACON
748 B-15
742-310
742-311
742-305,-307
742-306
742-309
742-304
742-303
742-302
742-308
742-322S
742-321S
742-320S
C4-S-57a
C4-S-1a
VC2-S-AP3
C1-M-AV1
C3-S-A2
C2-S-AJ1
C1A
C4-ST-67a
C3-ST-14a
T2-SE-A1

Fig. 59



P/LX R
% OVERALL x (L/D)
MED TANKER 16.70 x 10^7 83.6
MANHATTAN 46.18 x 10^7 116.7
2MC-2 .423 x 10^3 2.36
15 TON P/L GEM 1.875 x 10^3 0.39
C1-M-AV1
T2 SE-A1
C2-S-AJ
C1A
C3-S-A2
VC2-S-AP
C3-ST-14a
742-320S
742-321S
742-303
742-302
MACON
742-310
742-304
742-305
742-309
742-308
742-311
742-307
742-306
ZPG-2
CL-44D-4
C-118A
C-124C
URM-2
C-54G
C-130E
C-135B
748 B-15
L-300, 707-320C
C-133A
742-322S
90 TON P/L GEM
$\eta_{OVERALL} \times \left(\frac{L}{D}\right)$
100
80
60
40
30
20
10
8
6
4
3
2
1
1
2
3
5
10
2
3
5
100
2
3
5
1000
2
3
5
10,000
2
3
5
100,000
(P/L) x R – 1000 SHORT TON –N.MI.

Fig. 60

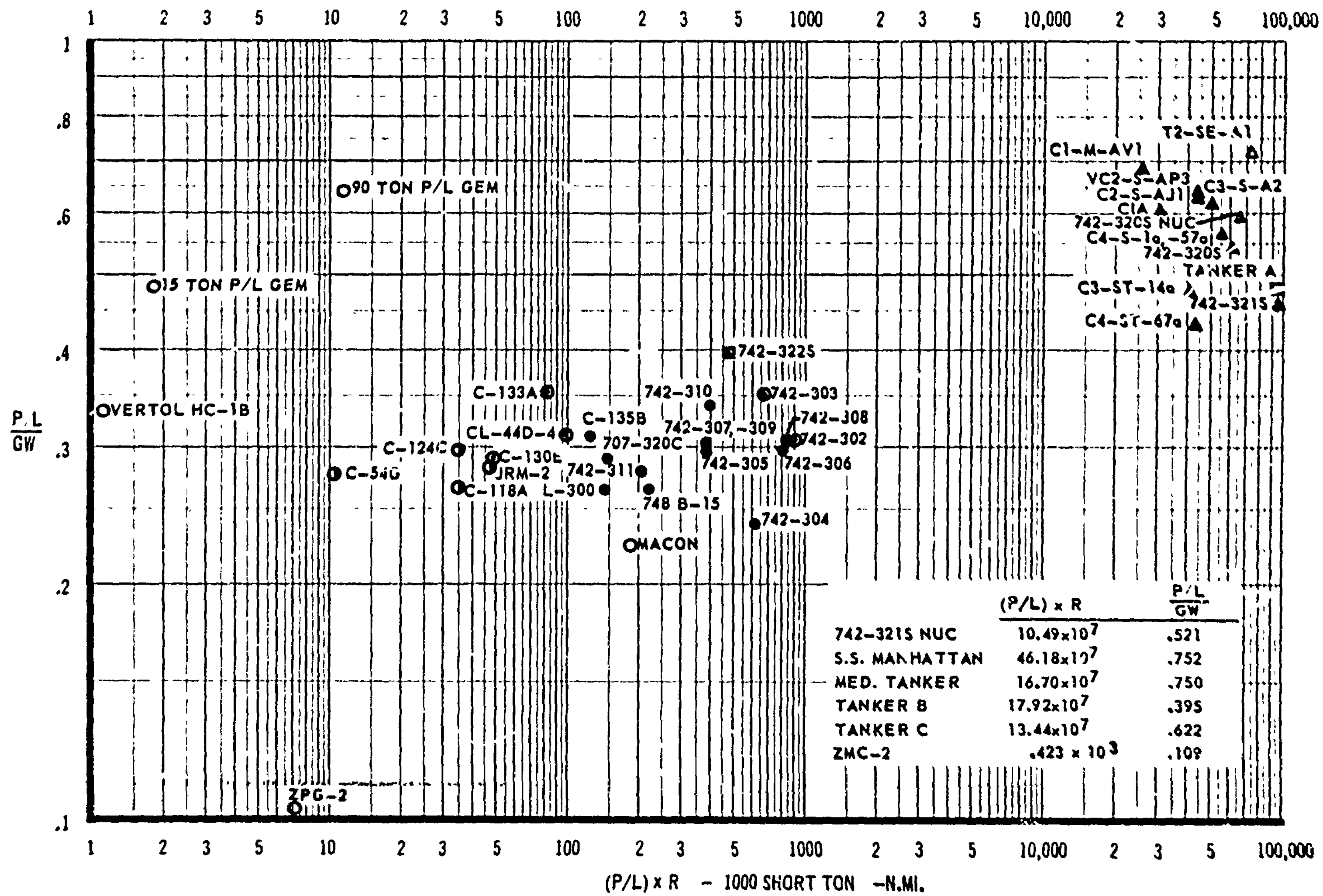

P.L / GW
(P/L) x R – 1000 SHORT TON –N.MI.
90 TON P/L GEM
15 TON P/L GEM
OVERTOL HC-1B
ZPG-2
C-54G
C-124C
C-118A
C-130E
JRM-2
CL-44D-4
C-133A
C-135B
707-320C
742-311
L-300
748 B-15
MACON
742-310
742-307, -309
742-305
742-322S
742-303
742-308
742-302
742-306
742-304
C1-M-AV1
T2-SE-A1
VC2-S-AP3
C2-S-AJ1
C3-S-A2
C1A
742-320S NUC
C4-S-1a, -57a
742-320S
TANKER A
C3-ST-14a
742-321S
C4-ST-67a
(P/L) x R
742-321S NUC 10.49x10^7 .521
S.S. MANHATTAN 46.18x10^7 .752
MED. TANKER 16.70x10^7 .750
TANKER B 17.92x10^7 .395
TANKER C 13.44x10^7 .622
ZMC-2 .423 x 10^3 .109

Fig. 61

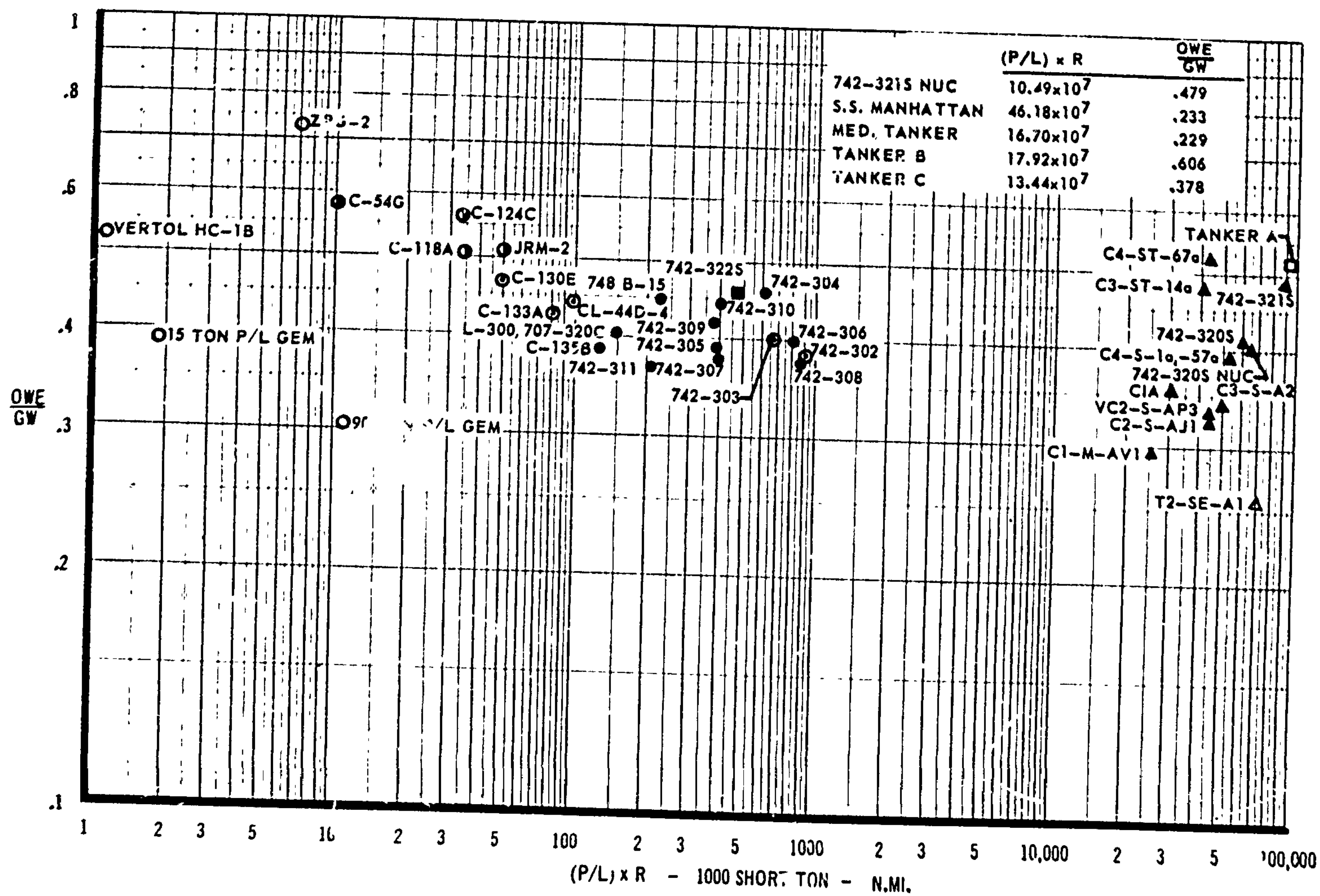
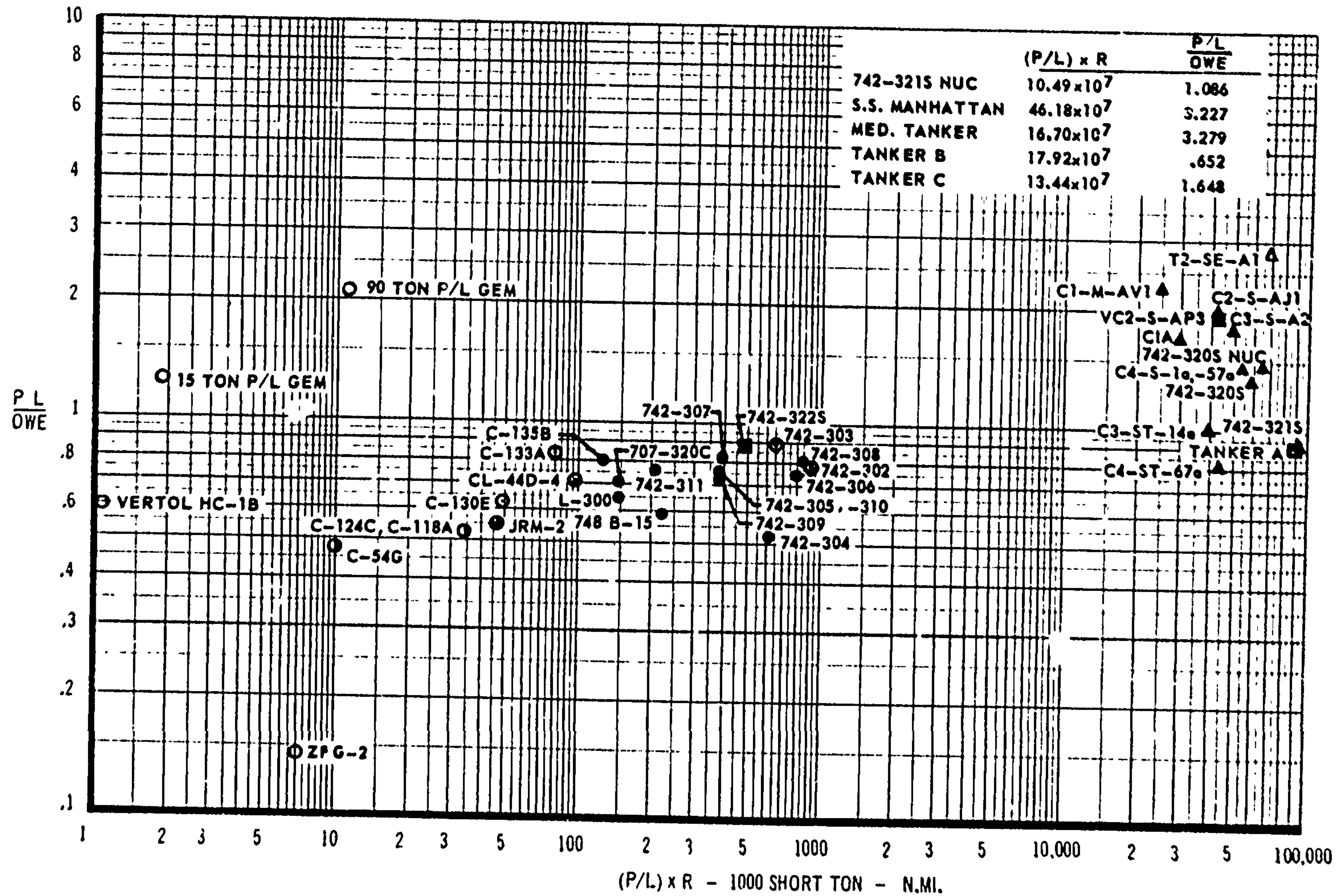

(P/L) x R
OWE/GW
742-321S NUC 10.49x10⁷ .479
S.S. MANHATTAN 46.18x10⁷ .233
MED. TANKER 16.70x10⁷ .229
TANKER B 17.92x10⁷ .606
TANKER C 13.44x10⁷ .378
VERTOL HC-1B
15 TON P/L GEM
C-54G
C-124C
C-118A
JRM-2
C-130E
748 B-15
C-133A
CL-44D-4
L-300, 707-320C
C-135B
742-322S
742-304
742-310
742-309
742-305
742-311
742-307
742-303
742-306
742-302
742-308
TANKER A
C4-ST-67a
C3-ST-14a
742-321S
742-320S
C4-S-1a,-57a
742-320S NUC
C1A
C3-S-A2
VC2-S-AP3
C2-S-AJ1
C1-M-AV1
T2-SE-A1
L GEM
(P/L) x R - 1000 SHORT TON - N.MI.
OWE/GW

Fig. 62



(P/L) x R
P/L / OWE
742-321S NUC 10.49x10^7 1.086
S.S. MANHATTAN 46.18x10^7 3.227
MED. TANKER 16.70x10^7 3.279
TANKER B 17.92x10^7 .652
TANKER C 13.44x10^7 1.648
90 TON P/L GEM
15 TON P/L GEM
VERTOL HC-1B
ZPG-2
C-54G
C-124C, C-118A
JRM-2
C-130E
CL-44D-4
C-133A
C-135B
707-320C
742-311
L-300
748 B-15
742-307
742-322S
742-303
742-308
742-302
742-306
742-305, -310
742-309
742-304
T2-SE-A1
C1-M-AV1
C2-S-AJ1
VC2-S-AP3
C3-S-A2
C1A
742-320S NUC
C4-S-1a,-57a
742-320S
C3-ST-14a
742-321S
TANKER A
C4-ST-67a
P L / OWE
(P/L) x R - 1000 SHORT TON - N.MI.

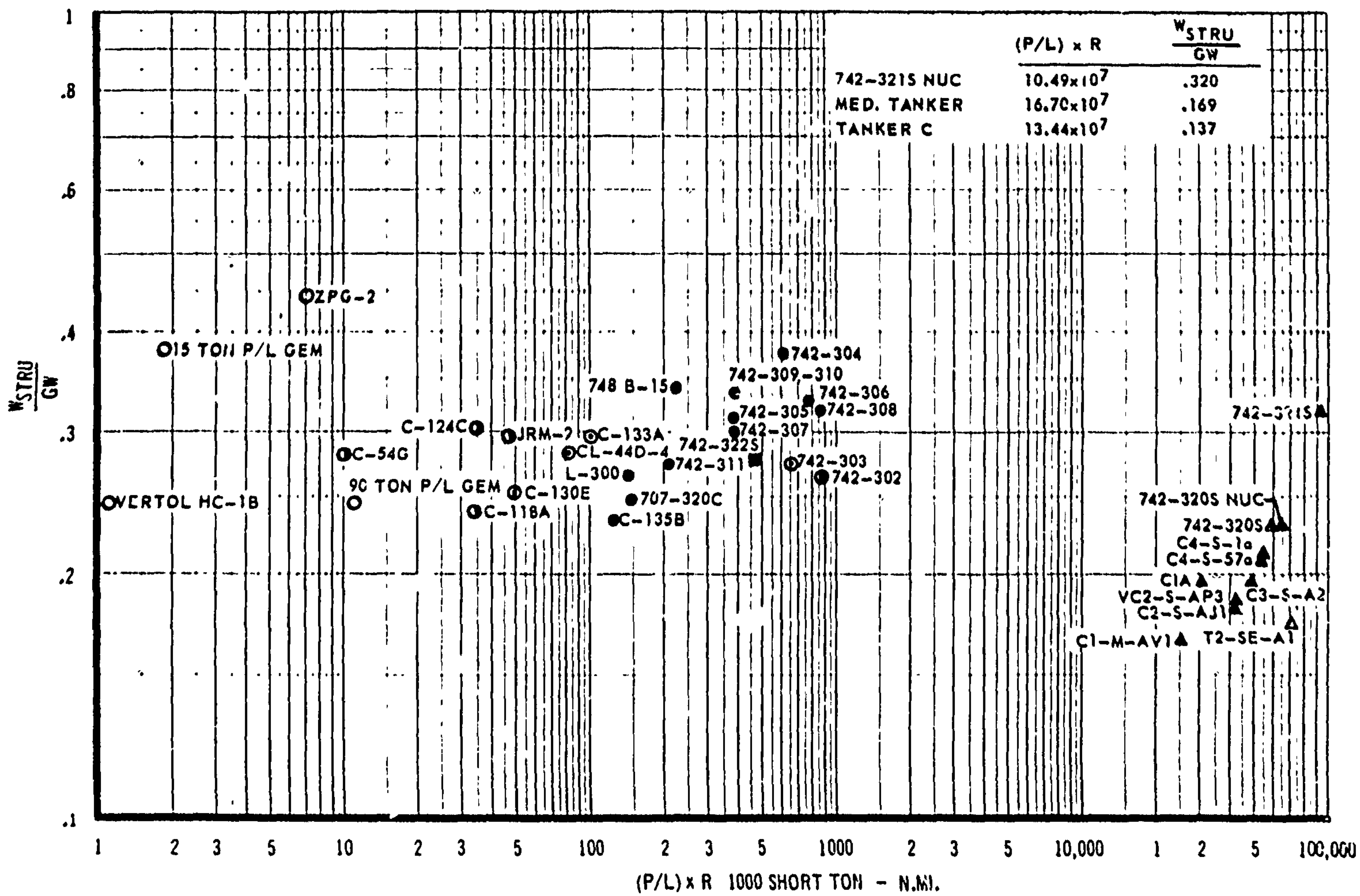
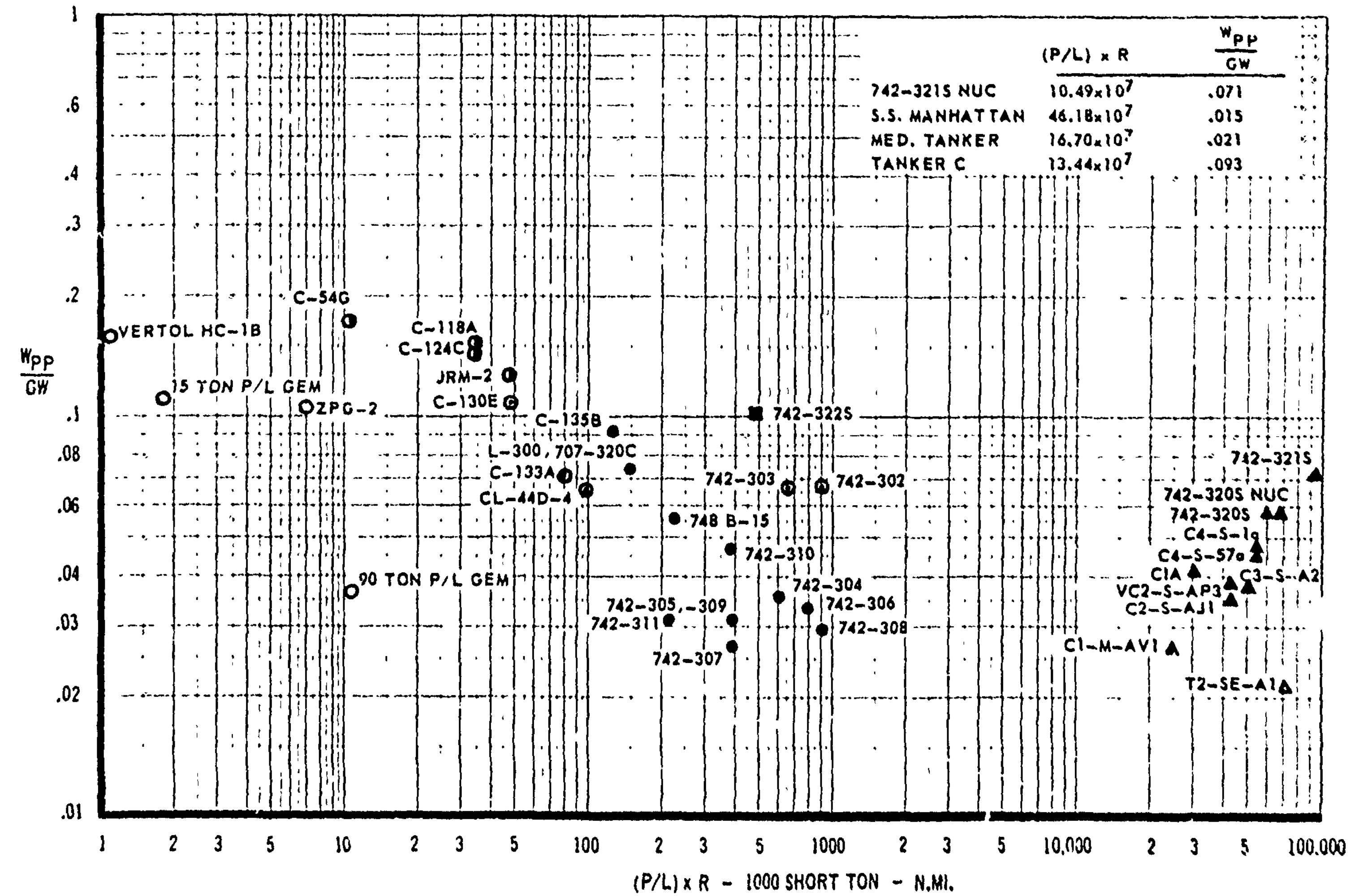
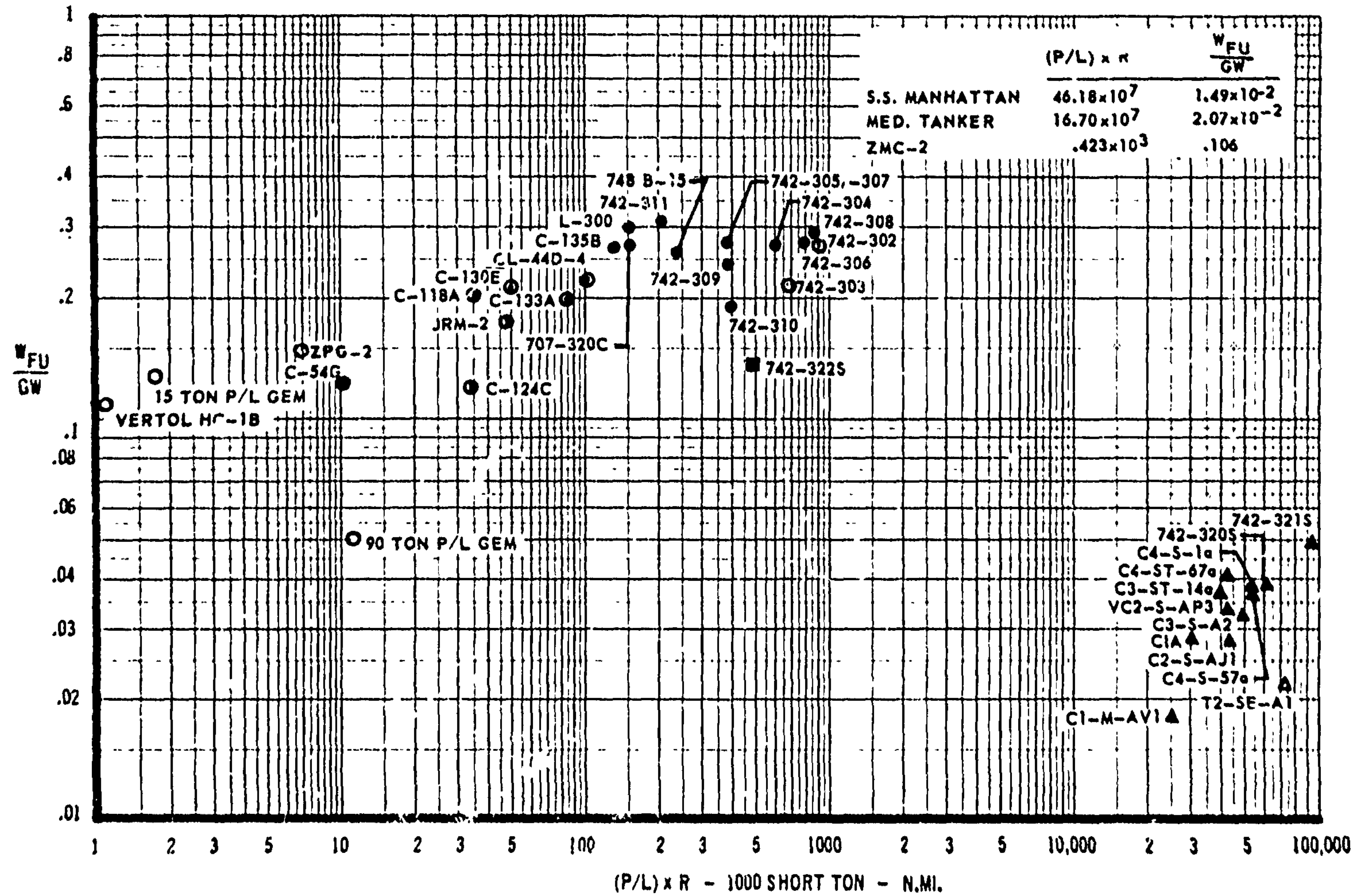

(P/L) x R
$\frac{W_{STRU}}{GW}$
742-321S NUC 10.49x10^7 .320
MED. TANKER 16.70x10^7 .169
TANKER C 13.44x10^7 .137
ZPG-2
15 TON P/L GEM
VERTOL HC-1B
C-54G
90 TON P/L GEM
C-124C
JRM-2
C-133A
CL-44D-4
L-300
C-130E
C-118A
707-320C
C-135B
748 B-15
742-304
742-309,-310
742-306
742-305
742-308
742-307
742-322S
742-311
742-303
742-302
742-320S NUC
742-320S
C4-S-1a
C4-S-57a
C1A
VC2-S-AP3
C3-S-A2
C2-S-AJ1
C1-M-AV1
T2-SE-A1
(P/L) x R 1000 SHORT TON - N.MI.

Fig. 64



(P/L) x R
$\frac{W_{PP}}{GW}$
742-321S NUC
10.49x10[7]
.071
S.S. MANHATTAN
46.18x10[7]
.015
MED. TANKER
16.70x10[7]
.021
TANKER C
13.44x10[7]
.093
VERTOL HC-1B
15 TON P/L GEM
ZPG-2
C-54G
C-118A
C-124C
JRM-2
C-130E
C-135B
L-300, 707-320C
C-133A
CL-44D-4
90 TON P/L GEM
742-322S
742-303
742-302
748 B-15
742-310
742-304
742-306
742-308
742-305, -309
742-311
742-307
742-321S
742-320S NUC
742-320S
C4-S-1a
C4-S-57a
C1A
C3-S-A2
VC2-S-AP3
C2-S-AJ1
C1-M-AV1
T2-SE-A1
$\frac{W_{PP}}{GW}$
1
.6
.4
.3
.2
.1
.08
.06
.04
.03
.02
.01
1
2
3
5
10
2
3
5
100
2
3
5
1000
2
3
5
10,000
2
3
5
100,000
(P/L) x R - 1000 SHORT TON - N.MI.

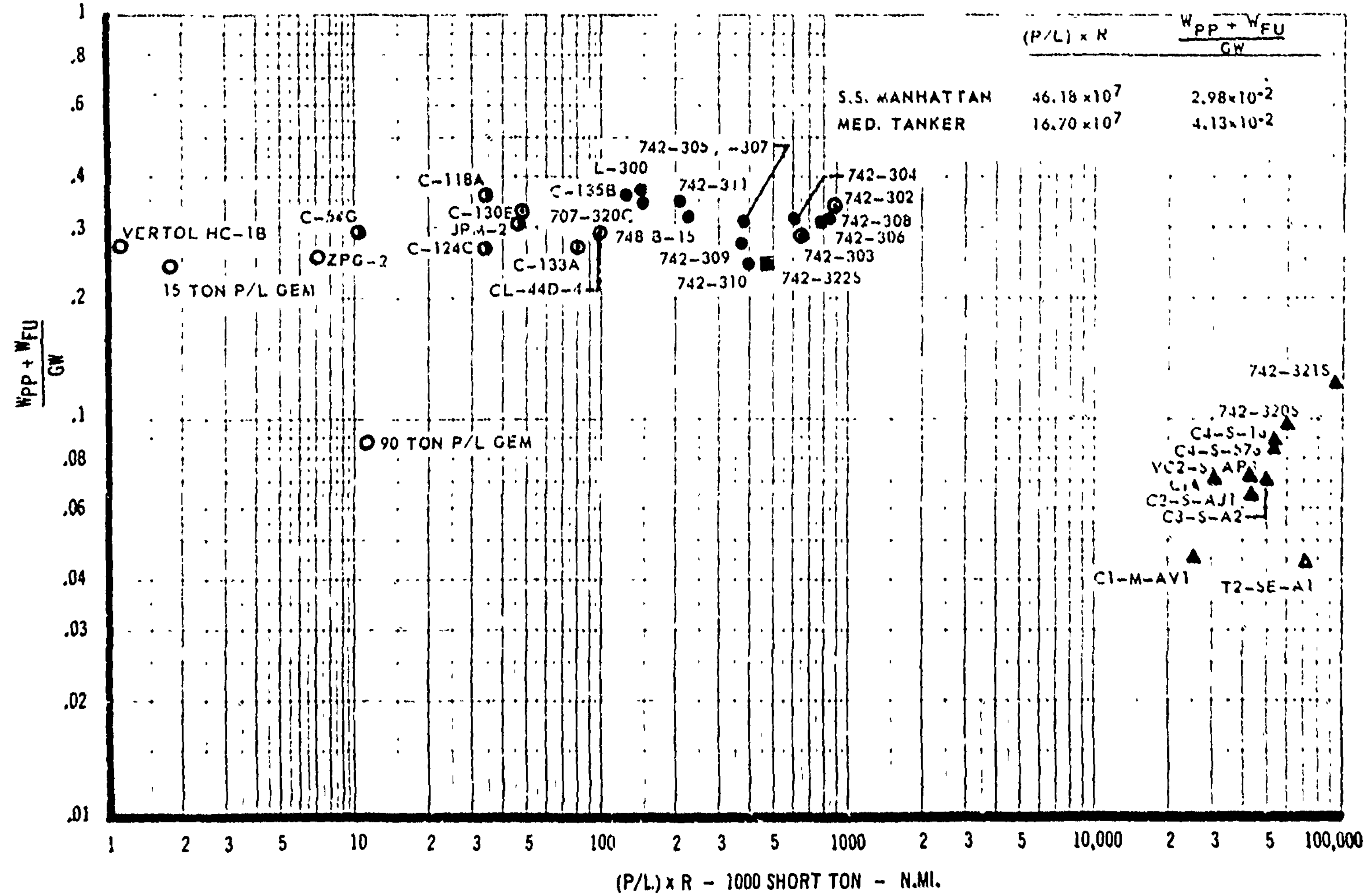
Fig. 65



	$(P/L) \times R$	$\frac{W_{FU}}{GW}$
S.S. MANHATTAN	46.18×10^7	1.49×10^{-2}
MED. TANKER	16.70×10^7	2.07×10^{-2}
ZMC-2	$.423 \times 10^3$	.106

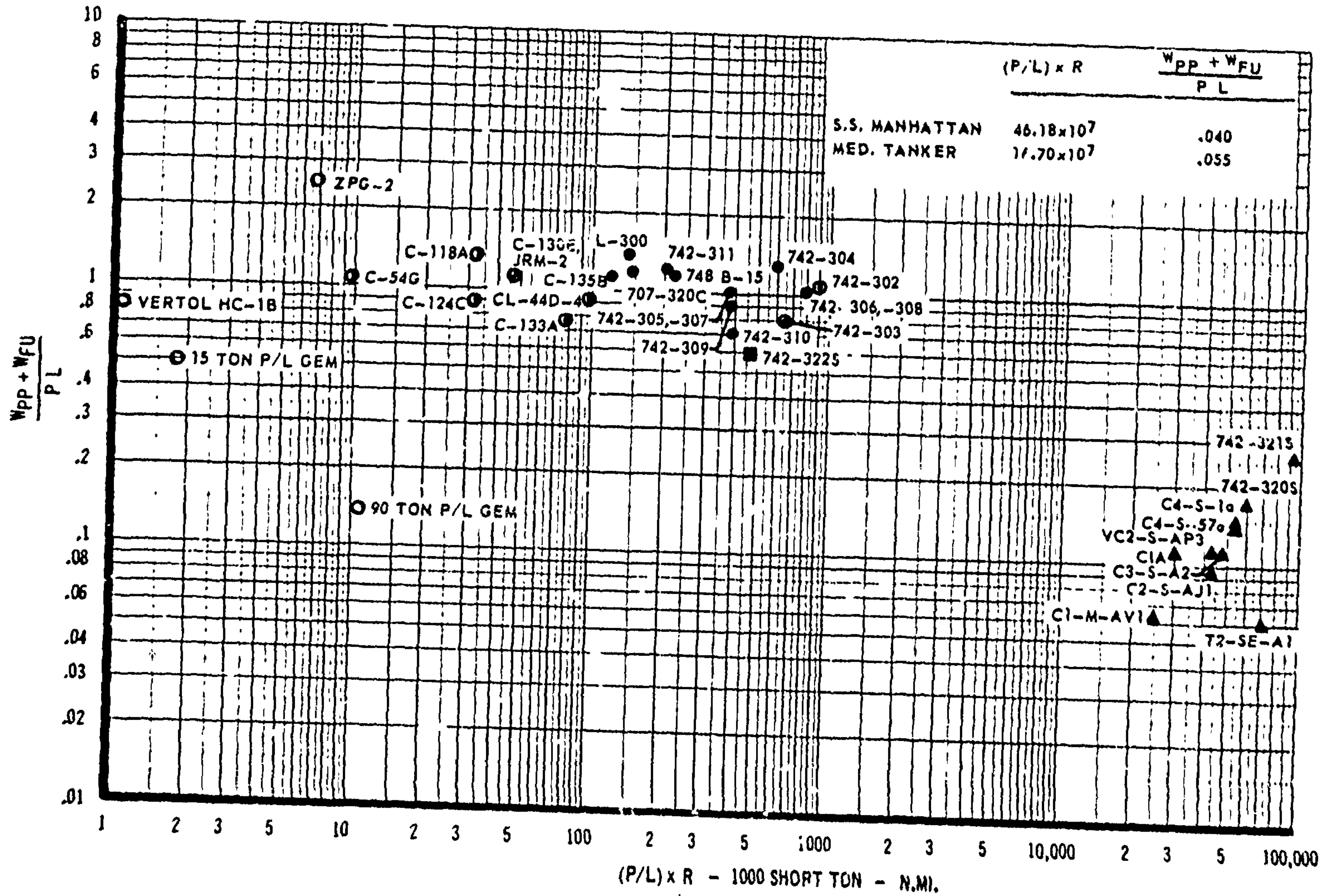
$\frac{W_{FU}}{GW}$
(P/L) x R - 1000 SHORT TON - N.MI.
VERTOL HC-1B
15 TON P/L GEM
C-54G
ZPG-2
90 TON P/L GEM
C-124C
JRM-2
C-118A
C-130E
C-133A
CL-44D-4
C-135B
L-300
742-311
748 B-15
707-320C
742-309
742-305, -307
742-304
742-308
742-302
742-306
742-303
742-310
742-322S
742-321S
742-320S
C4-S-1a
C4-ST-67a
C3-ST-14a
VC2-S-AP3
C3-S-A2
C1A
C2-S-AJ1
C4-S-57a
T2-SE-A1
C1-M-AV1

Fig. 66



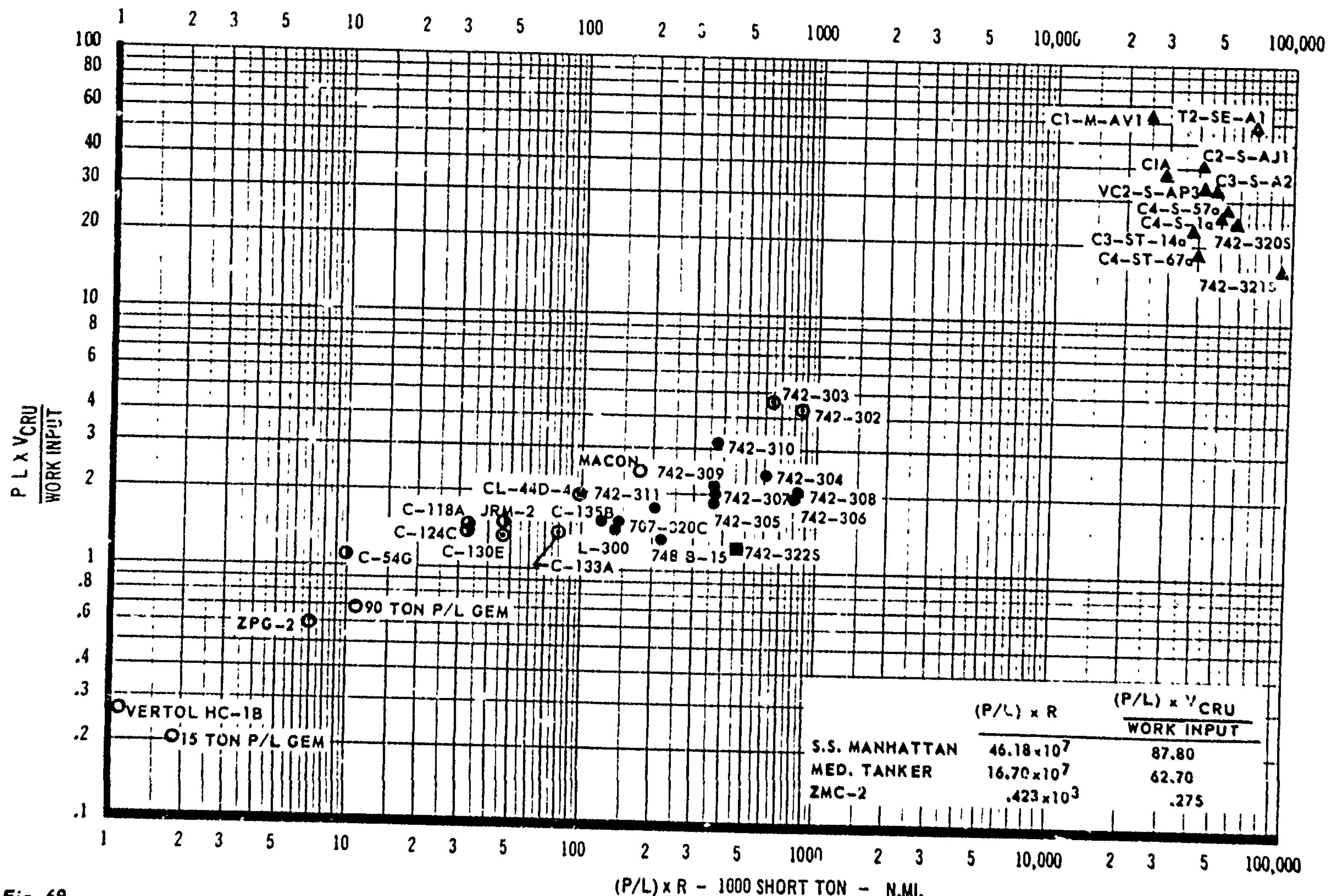
(P/L) x R
$\frac{W_{PP} + W_{FU}}{GW}$
S.S. MANHATTAN 46.18 x 10^7 2.98 x 10^-2
MED. TANKER 16.70 x 10^7 4.13 x 10^-2
VERTOL HC-1B
15 TON P/L GEM
C-54G
ZPG-2
90 TON P/L GEM
C-118A
C-130E
C-124C
C-133A
CL-44D-4
C-135B
L-300
707-320C
742-305, -307
742-311
742-309
742-310
742-304
742-302
742-308
742-306
742-303
742-322S
742-321S
742-320S
C3-S-A2
C1-M-AV1
T2-SE-A1
(P/L) x R - 1000 SHORT TON - N.MI.

Fig. 67



(P/L) x R
$\frac{W_{PP} + W_{FU}}{P\ L}$
S.S. MANHATTAN 46.18x10^7 .040
MED. TANKER 17.70x10^7 .055
ZPG-2
VERTOL HC-1B
15 TON P/L GEM
90 TON P/L GEM
C-54G
C-118A
C-124C
C-130E, JRM-2
C-135B
CL-44D-4
C-133A
L-300
742-311
748 B-15
707-320C
742-305,-307
742-309
742-310
742-322S
742-304
742-302
742-306,-308
742-303
742-321S
742-320S
C4-S-1a
C4-S-57a
VC2-S-AP3
C1A
C3-S-A2
C2-S-AJ1
C1-M-AV1
T2-SE-A1
(P/L) x R - 1000 SHORT TON - N.MI.

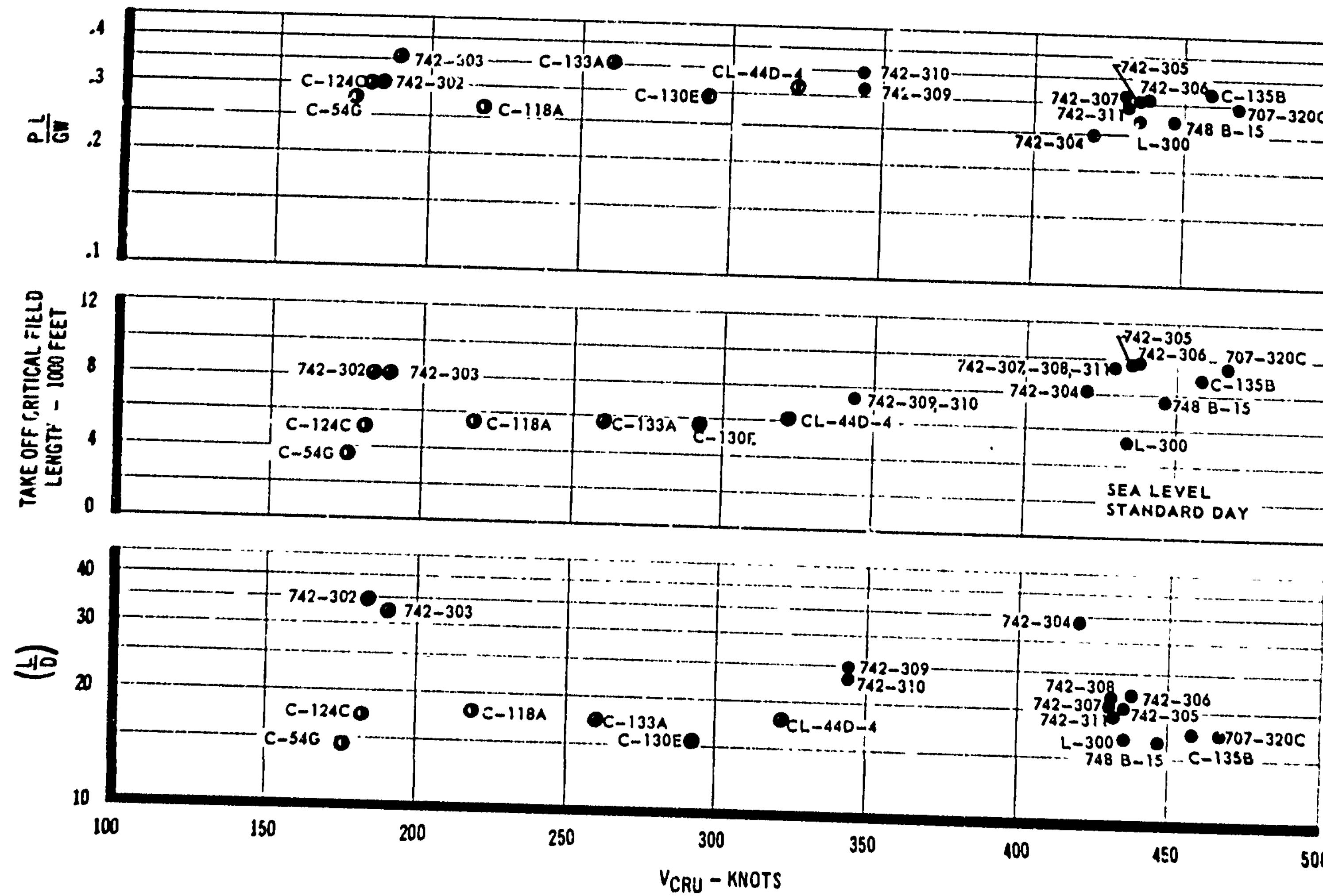
Fig. 68



$\frac{P\ L \times V_{CRU}}{WORK\ INPUT}$
(P/L) x R – 1000 SHORT TON – N.MI.
C1-M-AV1
T2-SE-A1
C1A
C2-S-AJ1
C3-S-A2
VC2-S-AP3
C4-S-57a
C4-S-1a
C3-ST-14a
742-320S
C4-ST-67a
742-321S
742-303
742-302
742-310
MACON
742-309
742-304
CL-44D-4
742-311
742-307
742-308
C-118A
JRM-2
C-135B
742-305
742-306
C-124C
707-320C
C-130E
L-300
748 B-15
742-322S
C-54G
C-133A
90 TON P/L GEM
ZPG-2
VERTOL HC-1B
15 TON P/L GEM
(P/L) x R
$\frac{(P/L) \times V_{CRU}}{WORK\ INPUT}$
S.S. MANHATTAN
46.18×10^7
87.80
MED. TANKER
16.70×10^7
62.70
ZMC-2
$.423 \times 10^3$
.275

Fig. 69

3.2.5 TAKEOFF FIELD LENGTH COMPARISON



742-303
742-302
C-124C
C-54G
C-118A
C-133A
C-130E
CL-44D-4
742-310
742-309
742-305
742-306
742-307
742-311
742-304
C-135B
707-320C
748 B-15
L-300
742-307,-308,-311
742-309,-310
SEA LEVEL
STANDARD DAY
742-308
$\frac{PL}{GW}$
TAKE OFF CRITICAL FIELD LENGTH - 1000 FEET
$\left(\frac{L}{D}\right)$
V_{CRU} - KNOTS

Fig. 70

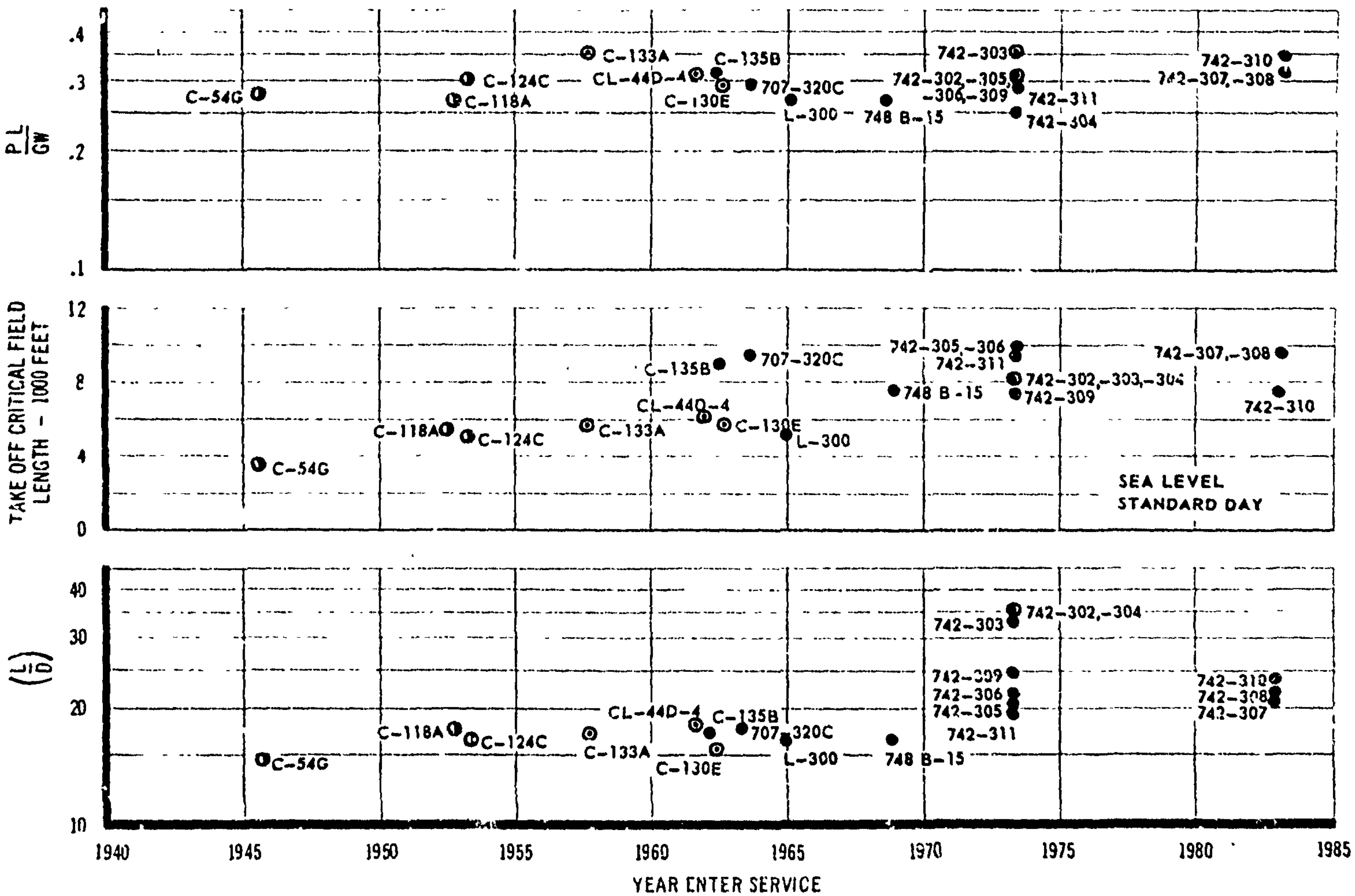

P.L / GW
TAKE OFF CRITICAL FIELD LENGTH - 1000 FEET
(L/D)
C-54G
C-118A
C-124C
C-133A
CL-44D-4
C-135B
C-130E
707-320C
L-300
748 B-15
742-303
742-302,-305
-306,-309
742-311
742-304
742-310
742-307,-308
742-305,-306
742-302,-303,-304
742-309
742-302,-304
SEA LEVEL
STANDARD DAY
YEAR ENTER SERVICE

Fig. 71

3.2.6 PAYLOAD-RANGE CURVES FOR STUDY VEHICLES

As discussed in Section 3.1 the vehicle's payload-range curve is a significant measure of its performance capability. Curves for the basic vehicles of this study are presented in Figs. 72 and 73. Curves for vehicles which are not included in the cost section are omitted.

The following ground rules are implicit in the curves:

(1) For aircraft

a) Standard day, no wind.

b) Reserve fuel equal to 10 percent of initial fuel on board.

c) Cruise altitude and speed are defined for maximum payload and maximum range. For the current military airplanes these values were taken from the applicable mission defined in the T. O. (Technical Order) or SAC (Standard Aircraft Characteristics) chart. For current commercial airplanes and the future airplanes it is maximum range cruise speed and altitude. (Except 742-302 and -303 LOBOYs are at sea level at speed for 97 percent maximum mile per pound.)

d) The fuel consumption is the actual predicted value. Degradation for compressor bleed and accessory drive is included. Conservatism, such as the 5 percent service tolerance of MIL-C-5011A, is not included.

e) Fuel consumption is included for

i) ground maneuver and takeoff
ii) climb
iii) cruise
iv) descent

Except for future aircraft, no range credit or fuel penalty for descent is included. At the long ranges of these aircraft this is a very minor item.

f) All aircraft weights and performance are based on 2.5 limit maneuver load factor except LOBOY which is 2.0.

(2) For ships

a) Average sea conditions and average sustained sea speed at normal power.

b) Reserve fuel equal to 25 percent of initial fuel on board, except hydrofoil craft 10 percent of initial fuel.

c) Miscellaneous weight on board including

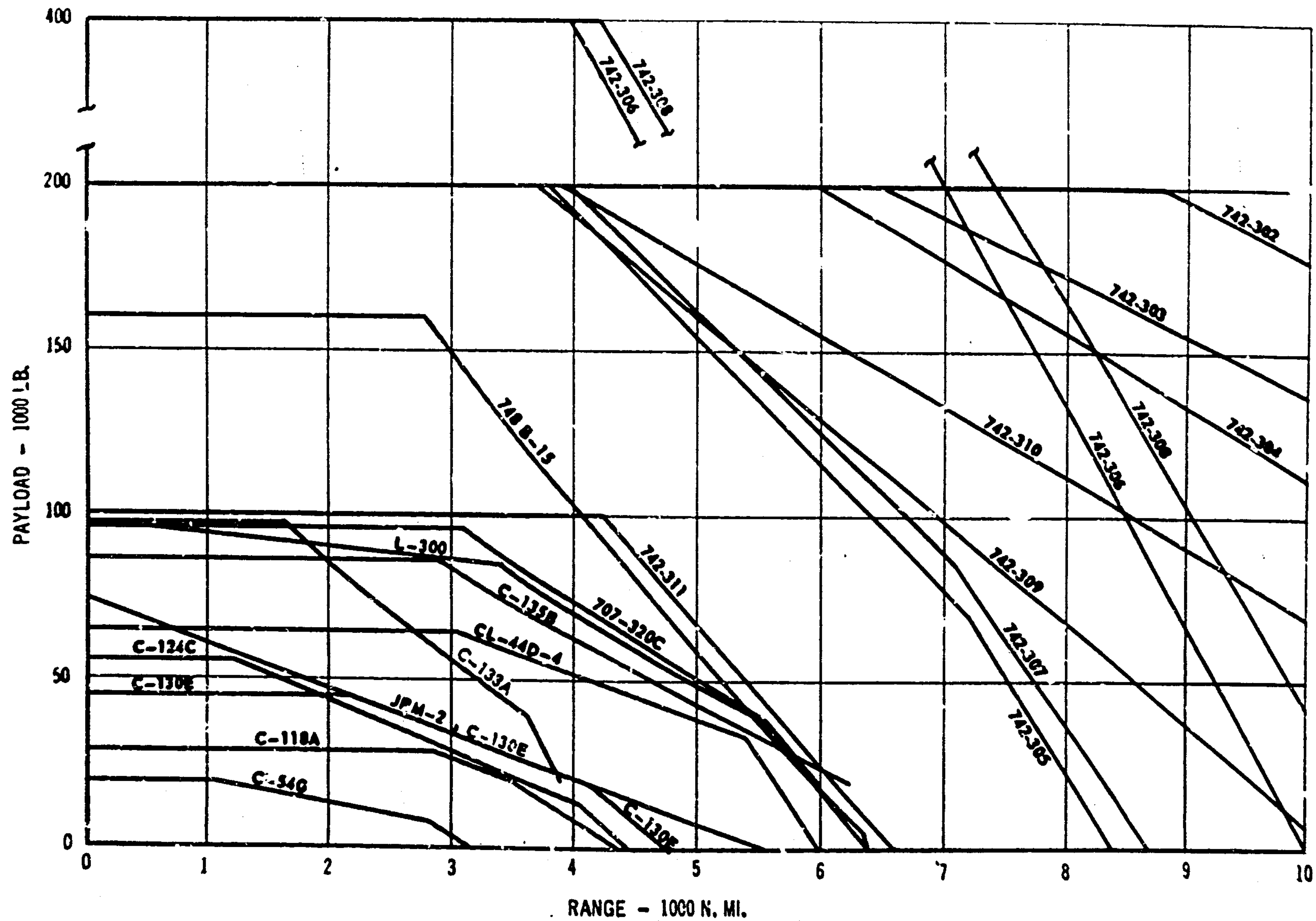


Fig. 72 Study Aircraft Payload/Range Characteristics

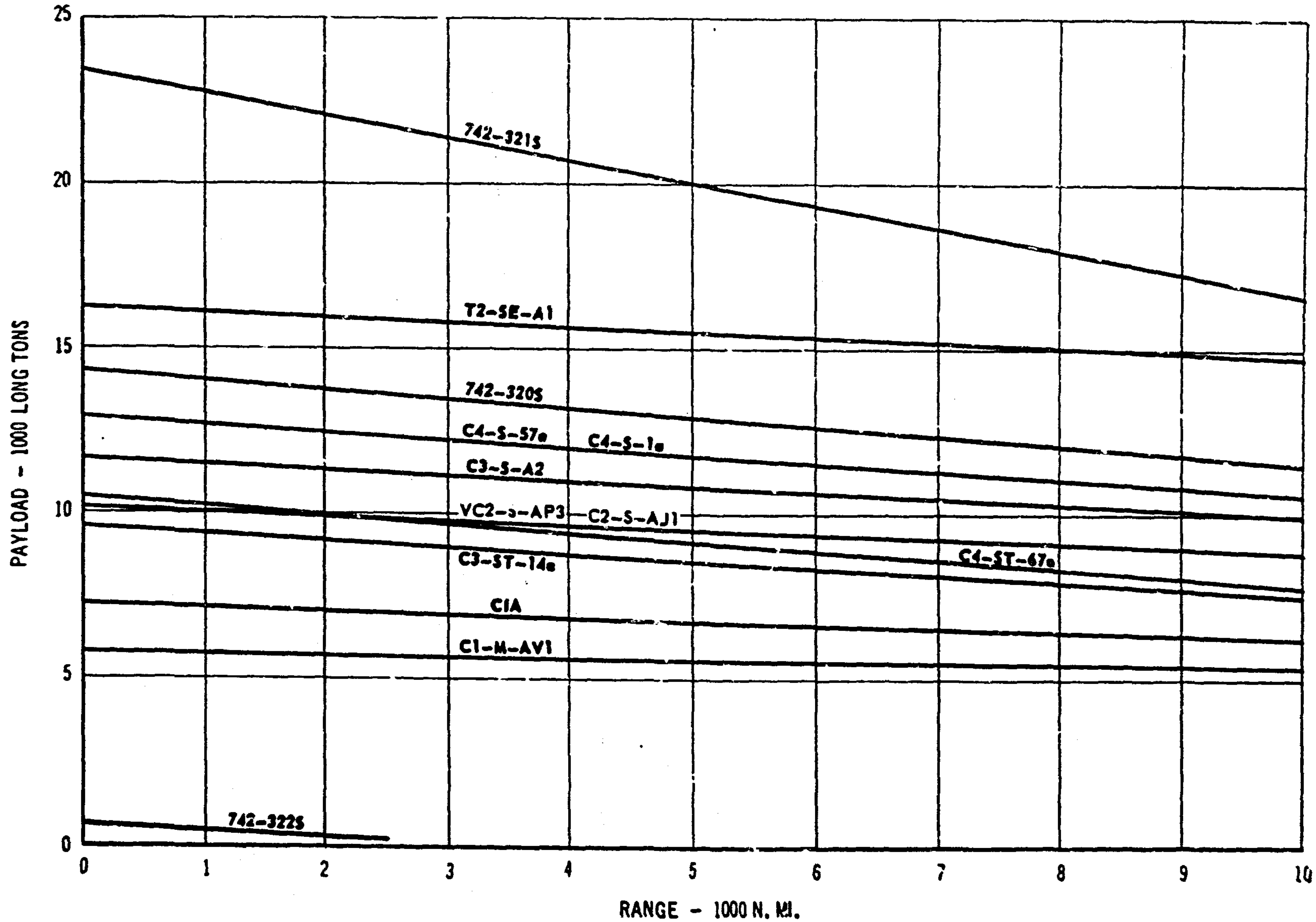


Fig. 73 Study Ship Payload/Range Characteristics

provisions, stores, crew and effects equal to 1/2 percent of total dead weight and dunnage equal to 1 percent of cargo dead weight.

d) Water on board equal to total capacity.
e) Fuel consumption is the actual quoted average at normal power for each current ship. Fuel consumption for future ships includes a 10 percent conservatism.
f) Fuel consumption is based on time at sea. Port fuel allowance is not included.

3.2.7 MARINE INNOVATION DATA

Several proposals have been discussed in the recent literature as offering the possibility of improved performance in marine transport. Fig. 74 taken from Ref. 26 summarizes data on four of these configurations. Successful development of these possibilities is necessarily dependent on a significant amount of research being completed and particularly on development of light, compact, high power propulsion machinery.

Inspection of Fig. 74 shows that the largest potential in speed and L/D may be expected from the deep running submarine. This speed potential is purchased at the expense of the most difficulty in practical design and operation.

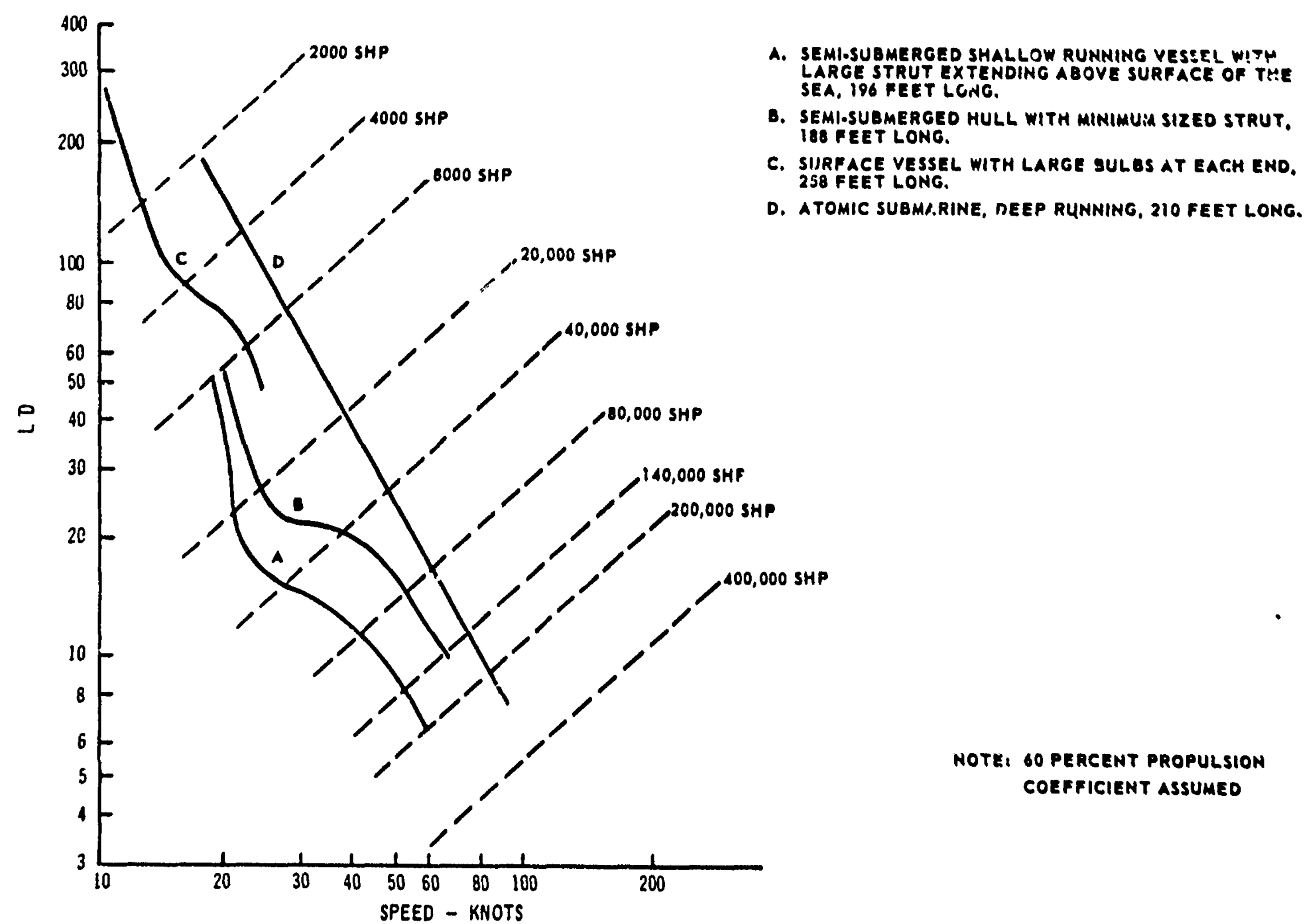


Fig. 74 2000 Ton Displacement Unusual Ship Forms

4.0 OPERATIONAL PARAMETER DATA

4.1 INTRODUCTION

The purpose of this section is to examine the effects of operational influences on transport aircraft and transport ships. Reliability, utilization, useful life, and environment are discussed as they apply to these transport vehicles. Specific data are presented where possible, although the data are necessarily more limited than that of Sections 3 and 5. The primary interest of this study is in cargo rather than passenger transport. Operational data for some passenger aircraft are presented where there is a lack of cargo data and where there is a similarity between passenger and cargo operations.

After comparing general influences of reliability, utilization, useful life, and environment on these aircraft and ships, two representative missions are exercised. The first task is a high density cargo movement to the Far East over a one year period (an example of a weight limited lift). The second is the deployment of an armored division to the Far East in thirty days (a space-limited example). These missions provide a basis for comparing the capabilities and costs for the various transport vehicles considered in Section 5.

4.2 RELIABILITY

4.2.1 GENERAL

Reliability is defined as the quality of performing as expected, when expected, during the vehicle's specified useful life. In all vehicles, the total reliability is a function of the reliabilities of all the components, subsystems, and systems of the vehicle.

The reliability of a given mode of transportation may be defined in terms of delays in scheduled operation, in the number and frequency of equipment failures, or in the probability of mission completion. The method used is dependent on the type of equipment involved and the type of information desired.

The following paragraphs discuss general methods by which reliability is affected or improved.

RELIABILITY BY DESIGN

Reliability is dependent on detail design, choice of materials, and specification of fabrication techniques. The reliable performance of subsystems and systems is dependent on careful selection of components, degree of redundancy, provision of parallel functions, and/or derating of items. Both the vehicle manufacturer and the operator pay for these features, and, thus, reliability is interrelated with safety and economics.

RELIABILITY BY MANUFACTURE

Manufacturing quality control, like reliability, is a matter of statistical analysis. Recognizing that quality control alone cannot prevent all design and manufacturing component failure from appearing in the finished vehicle, manufacturers normally extend a warranty against defective parts and/or labor for a specified length of time or service. These failures are represented graphically by the left hand portion of the curve in Fig. 75.

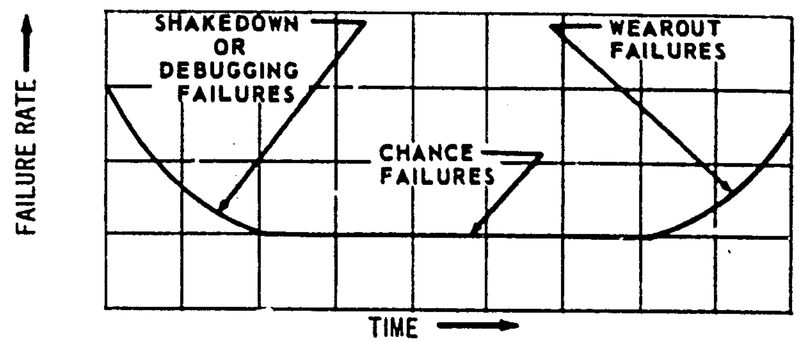


Fig. 75 Typical Failure Rate Curve

RELIABILITY BY SCHEDULE ADJUSTMENT

With all vehicles, schedule reliability is of considerable significance. This is defined as the ratio of the total trips which are initiated within a specified time of a scheduled departure, divided by the total number of trips planned.

Schedule reliability is dependent on the total number of vehicles available as compared to the number of vehicles scheduled. Where necessary and available, spare vehicles may be used to replace those which are scheduled to depart, but which are out of service because of component failure.

Schedule reliability of vehicles may be drastic-

ally affected by maintainability. Maintainability is defined as the condition describing the relative ease and speed with which deficiencies can be corrected once they are discovered. Factors which influence maintainability are the degree of simplicity or complexity of the equipment involved, its accessibility, the ease with which trouble shooting can be accomplished, and the facility of replacement or repair once the trouble has been isolated. Also affecting schedule reliability are trip duration and turn-around time when considering vehicle substitution or route over-lapping techniques.

4.2.2 TRANSPORT AIRCRAFT RELIABILITY

4.2.2.1 GENERAL

In the case of transport airplanes, the most widely used reliability is schedule reliability, or probability of adherence to a predetermined schedule of operation. It is chosen for discussion here.

Factors which affect schedule reliability may be classed as controllable and uncontrollable. The major uncontrollable factor is weather. The delay, cancellation or rerouting of flights due to weather conditions has customarily not been included in schedule delay studies. However, the advent of equipment and techniques permitting all-weather airplane operation will, in the future, cause greater consideration of weather as a semi-controllable schedule delay cause. Controllable factors which affect schedule reliability include:

- Fleet Size: One method used in commercial fleets to lessen the effects of flight delays and cancellations due to mechanical failures is airplane substitution. Typically 3 to 4 percent of all commercial flights are operated after substitution of an airplane to avoid departure delays.

  Economic considerations such as the total number of airplanes in the fleet and the potential revenue loss due to delay dictate the number of "spare" airplanes made available for substitution.

- Flight Duration: The highest equipment failure incidence generally occurs during starting, warmup or some initial phase

of operation appropriate for the equipment involved. It follows that the greater the number of flights conducted per airplane, the greater will be the probability of a delay due to mechanical failure. An airplane operated on a short flight basis will be more likely to experience schedule delays than an airplane assigned to long flights within a given time span.

- Turn-around Time: Turn-around time is defined as the amount of time necessary to deplane passengers, baggage and/or cargo, clean and service the airplane, and reload for new or continued mission. In commercial service, there is normally no provision in this activity to perform any but minor maintenance. Schedule delays may, therefore, be reduced through extension of turn-around time, but this, too, is controlled by economic factors.

- Route Scheduling: Equally important to ensure schedule reliability is flight schedule overlapping to provide standby airplanes in the event malfunctioning airplanes cannot be repaired in the scheduled time available. All commercial airlines attempt to use the overlapping schedule technique. Where overlapping cannot be provided, a schedule will be particularly vulnerable to delay.

4.2.2.2 RELIABILITY DATA

The data in Table 7 was compiled from operational records of a commercial airline using turbojet, turbofan, turboprop, and reciprocating engine powered transport airplanes. The records covered a period of 27 months (September 1961 through November 1963). Table 7 data does not deal in specific equipment item failures but rather in equipment items which were removed before the scheduled overhaul time. These removals could be the result of erroneous trouble diagnosis, for convenience of maintenance, or because of malfunction.

For purposes of comparison, the information in Table 8 was tabulated from data on regularly scheduled flights by Military Air Transport Service (MATS). It encompasses 12 months of operation (January 1962 through January 1963)

Table 7 Failure and Schedule Data For Transport Airplanes

SYSTEM/EQUIPMENT	TURBOJET AND TURBOFAN TRANSPORTS				TURBOPROP TRANSPORTS		
	Number Unsched. Removals	Percent of Total Removals	Schedulo Interrupt. Caused	Percent of Total Interrupt.	Number Unsched. Removals	Percent of Total Removals	Schedule Interrupt. Caused
1. Air Conditioning	1459	6.9	92	6.4	4316	10.3	245
2. Auto Pilot	757	3.6	23	1.6	1395	3.3	16
3. Communications	2032	9.7	19	1.3	2672	6.4	65
4. Electrical	1493	7.1	64	4.4	1530	3.6	326
5. Fire Protection	340	1.6	44	3.1	283	0.7	42
6. Flight Controls	578	2.7	79	5.4	731	1.8	146
7. Fuel	412	2.0	40	2.8	1026	2.5	124
8. Hydraulic	511	2.4	88	6.1	1744	4.2	220
9. Ice/Rain Protection	146	.7	15	1.1	930	2.2	51
10. Instruments	192	.9	-	-	352	0.8	6
11. Landing Gear	883	4.2	251	17.4	648	1.6	567
12. Lights	600	2.9	29	2.0	994	2.4	137
13. Navigation	3719	17.7	115	8.0	4839	11.6	369
14. Oxygen	1542	7.3	30	2.1	1901	4.6	41
15. Structures	508	2.4	42	2.9	1315	3.1	224
16. Cowling	193	.9	6	.4	400	1.0	8
17. Engines	731	3.5	68	4.7	447	1.1	282
18. Engine Controls	9	.1	4	.3	42	-	-
19. Engine Fuel and Controls	603	2.9	59	4.1	1645	3.8	137
20. Engine Indicating	1139	5.4	18	1.2	3042	7.3	132
21. Ignition	260	1.2	16	1.1	52	0.1	25
22. Exhaust	1102	5.2	85	5.9	1238	3.0	12
23. Oil	516	2.5	68	4.7	2035	4.9	132
24. Starting	639	3.0	107	7.4	2056	4.9	140
25. Air	649	3.1	80	5.6	511	1.2	52
26. Propellers	-	-	-	-	5661	13.6	597
TOTALS	21,013	100.0	1,442	100.0	41,805	100.0	4044
TOTAL MISSIONS	42,253				141,558		
TOTAL FLIGHT HOURS	36,760				140,172		
FLIGHT HOURS/MISSION	Avg. .87 hrs with a Min. of .50 hrs. and Max. of 1.30 hrs. in the selected missions				Avg. .99 hrs with a Min. of .90 hrs. 1.10 hrs. in the selected missions		

D TURBOFAN ORTS		TURBOPROP TRANSPORTS				PISTON ENGINE TRANSPORTS			
Schedule Interrupt. Caused	Percent of Total Interrupt.	Number Unsched. Removals	Percent of Total Removals	Schedule Interrupt. Caused	Percent of Total Interrupt.	Number Unsched. Removals	Percent of Total Removals	Schedule Interrupt. Caused	Percent of Total Interrupt.
92	6.4	4316	10.3	245	6.0	7402	8.6	324	3.5
23	1.6	1395	3.3	16	0.4	INCOMPLETE INFORMATION			
19	1.3	2672	6.4	65	1.6	5510	6.4	302	3.3
64	4.4	1530	3.6	326	8.1	4226	4.9	601	6.5
44	3.1	283	0.7	41	1.0	1527	1.8	427	4.5
79	5.4	731	1.8	146	3.6	983	1.2	104	1.1
40	2.8	1026	2.5	124	3.1	3061	3.6	232	2.5
88	6.1	1744	4.2	220	5.4	1974	2.3	285	3.1
15	1.1	930	2.2	51	1.3	1671	1.9	95	1.0
-	-	352	0.8	6	0.1	INCOMPLETE INFORMATION			
251	17.4	648	1.6	567	14.0	4285	5.0	1511	16.3
29	2.0	994	2.4	137	3.4	1049	1.2	345	3.7
115	8.0	4839	11.6	369	9.1	7010	8.2	290	3.1
30	2.1	1901	4.6	41	1.0	2724	3.2	31	0.3
42	2.9	1315	3.1	224	5.5	1440	1.7	302	3.3
6	.4	400	1.0	8	0.2	2533	2.9	127	1.4
68	4.7	447	1.1	282	5.7	4904	5.7	1397	15.4
4	.3	42	-	-	-	1132	1.3	81	0.9
59	4.1	1645	3.8	137	3.4	5272	6.1	231	2.5
18	1.2	3042	7.3	132	3.3	6389	7.4	133	1.4
16	1.1	52	0.1	25	0.6	15347	17.9	1227	13.2
85	5.9	1238	3.0	12	0.3	2809	3.3	170	1.8
68	4.7	2035	4.9	132	3.3	1978	2.3	234	2.5
107	7.4	2056	4.9	140	3.5	299	0.3	202	2.2
80	5.6	511	1.2	52	1.3	-	-	-	-
-	-	5661	13.6	597	14.8	2392	2.8	621	6.7
1,442	100.0	41,805	100.0	4044	100.0	85,917	100.0	9272	100.0
53		141,558				309,950			
30		140,172				409,134			
.50 hrs. and Max. of sions		Avg. .99 hrs with a Min. of .90 hrs. and a Max. of 1.10 hrs. in the selected missions				Avg. 1.32 hrs with a Min. of .58 hrs. and a Max. of 1.52 hrs. in the selected missions			

Table 8 Schedule Reliability Mats Operation

	TURBOJET TURBOFAN TRANSPORTS	TURBOPROP TRANSPORTS	PISTON ENGINE TRANSPORTS		TURBOJET & TURBOFAN TRANSPORTS
	C-135B	C-133	C-124	C-118	FUTURES
DEPARTURES INTERRUPTED (MAINTENANCE)	6.70%	10.35%	7.51%	5.70%	3%
DEPARTURES INTERRUPTED (ALL CAUSES)	22.10%	28.19%	20.93%	12.34%	10%
PROBABILITY OF ON-SCHEDULE DEPARTURE (MECHANICAL DELAYS ONLY)	93.30%	89.65%	92.49%	94.30%	97%
PROBABILITY OF ON-SCHEDULE DEPARTURE (ALL CAUSE DELAYS)	77.90%	71.81%	79.07%	87.66%	90%
ENGINE PREMATURE REMOVAL RATE PER 1000 ENGINE HRS.	0.642	2.9	0.9	0.8	0.2
FLIGHT HOURS	25,280	32,899	136,696	60,082	
NO. DEPARTURES	3,988	4,814	17,164	11,691	

for which reports were available on similar types of aircraft.

The figures shown in the right hand column are projections for possible future turbojet/turbofan MATS transports. These figures were derived from experience with current commercial transports.

Maintenance facilities and personnel experience will affect the schedule reliability. Characteristically, this is shown in the early operation on any new airplane. Fig. 76 shows that it takes approximately one to two years for operator personnel to become familiar with the airplane, and to learn maintenance of its systems. The data for plotting these curves were derived from operation records of all commercial airlines operating Boeing 707 jet airplanes during a selected 24 month period. The data are based on the ground rule that a schedule delay is 15 minutes or more after schedule takeoff time. The 15 minute period is the same standard for both military and commercial operations. The curves show the difference in the rate that potential schedule reliability will be achieved with and without

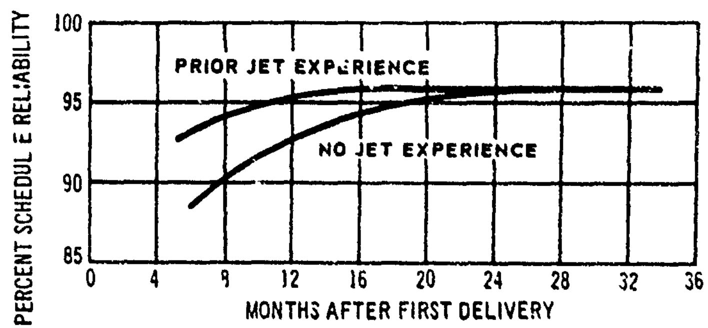


Fig. 76 Experience Factor In Attaining Schedule Reliability

prior experience with jet transport airplanes.

Fig. 77 shows the comparative operational reliability of reciprocating engine, turboprop, and turbojet/fan powered airplanes, respectively. These data were taken from the domestic operations of a typical commercial trunk airline operating the above types of airplanes during September, October, and November of 1963.

Using the delays of 15 minutes and over for a one hour flight, as shown on the left hand side of Fig. 77, the operational reliability is 98.1 percent for reciprocating engine airplanes, 98.15 percent for turboprop airplanes and 97.9 percent for turbojet/fan airplanes.

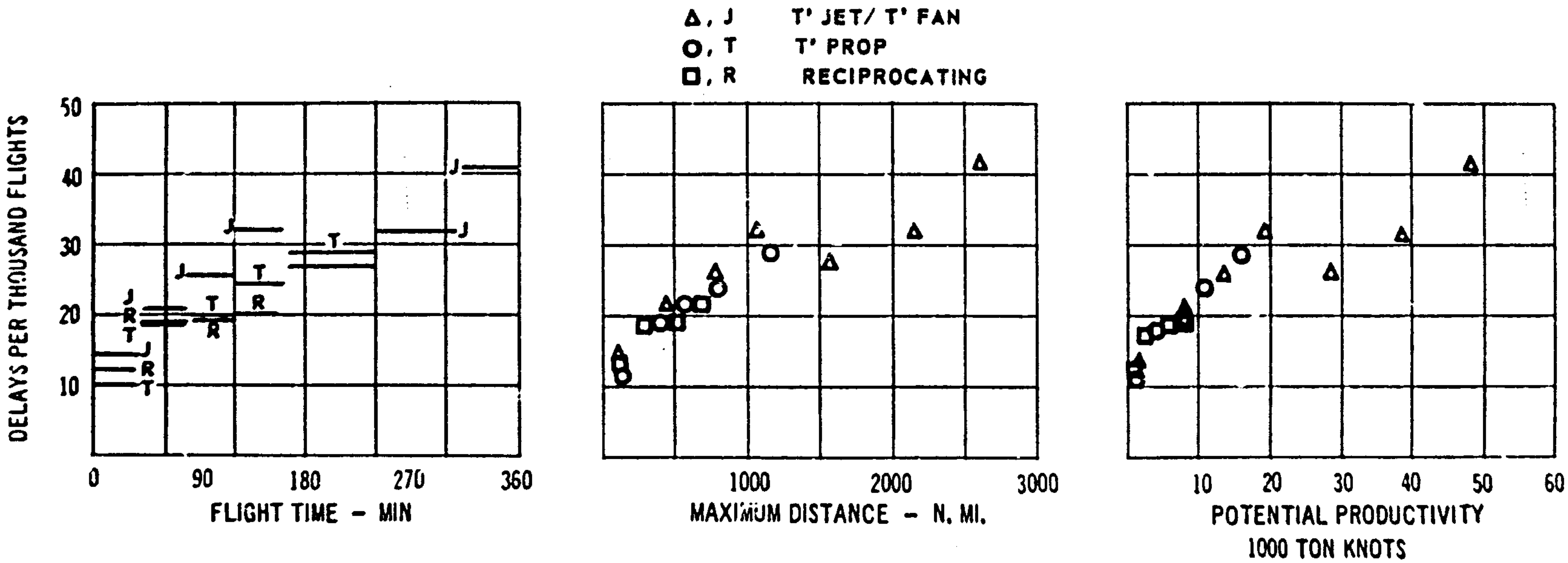


Fig. 77 Comparative Operational Reliability

The above values do not reflect the turbojet/fan airplane work rate capability. Since these airplanes are much larger and faster, the work rate is an important basis for comparison. On the basis of 10,000-ton nautical miles of work for a one hour flight length, the comparable schedule reliability would be 94.5 percent for the reciprocating engine aircraft, 96.1 percent for the turboprop airplanes and 97.5 percent for the turbojet/fan aircraft.

The right hand portion of Fig. 77 shows how the number of delays varies with flight distance and productivity.

4.2.3 TRANSPORT SHIPS

Reliability is viewed and handled by ship operators in a somewhat different fashion from that of aircraft manufacturers and operators. The overall reliability for a ship is kept very high by the carrying of spare parts and maintenance

personnel. Individual component failure rates are probably higher than those for equivalent aircraft parts, although proof of this statement is impossible due to the lack of adequate data.

For this study, the search for part failure rates and reliability data included contacts with commercial and military ship operators and with BuShips. It was determined that operators do not maintain records of part failures in sufficient detail to allow any satisfactory statistical analysis. The point was made that the cost of maintaining such records is not warranted by the potential savings involved. BuShips personnel advised that statistical analyses on large numbers of fleet ship components have been started. However, the cataloging system for these data is still incomplete. In addition, the first interest in these reliability analyses is for electronic systems which are not common to cargo ships. Because of these facts and the obviously large effort involved in gathering BuShips data, it was decided that such an investigation was not warranted in this study.

The nature of transport ship operation is such that it permits a wide latitude of methods and techniques for assuring reliable operation. Some of these factors, which tend to promote overall ship reliability, are discussed in the following paragraphs.

- Simplicity of Design: Compared to aircraft, the systems required for proper ship operation are relatively uncomplicated. This simplicity of design and function helps to ensure the reliability of ship operation by decreasing the number of potential failures, and increasing the ease with which these failures can be corrected if and when they occur.

- Redundancy of Machinery: Because a lower power penalty is paid for weight on a ship than in other types of transport vehicles, reserve components and systems are both practical and desirable.

- Interconnection of Function: The similarity of machinery in various systems, and the parallel nature of the systems themselves, permit installation so that they

can perform for one another in the event of need or emergency.

- Derating: A common technique for gaining additional usefulness and reliability from an item is to place it into a service environment that is less severe than that for which it was designed. In this way, the item will normally perform reliably for a period far in excess of its rated life, and will be capable of safely assuming higher loads should the need arise.

- Frequency of Servicing and Maintenance: Skilled repair technicians are part of the ship's crew. These personnel are assigned to perform varying degrees of preventive maintenance on a continuing basis.

- Stability of Operation: The nature of ship operation lends itself to stabilized operation over extended periods of time. Since many premature failures may be attributed to stresses incurred in start up and shut down, normal ship operation will tend to minimize these failures.

4.3 UTILIZATION

4.3.1 GENERAL

Utilization as applied to a transport vehicle may be construed to have two meanings - operational utilization and loading utilization. Operational utilization is perhaps the more common, and is defined as being the ratio of the amount of time a vehicle is employed in productive use during a given period, compared to the total time in that period. Loading utilization, or load factor, is the ratio of the amount of cargo which is carried compared to the maximum quantity which can be carried.

The degree of utilization of transport vehicles depends upon the characteristics of the vehicle and the type of service it is required to perform. Characteristics influencing utilization include vehicle dimensions, performance, maintainability, and ease of servicing. Types of usage are divided into the broad classifications of military and commercial. While these factors tend to influence both operational and cargo utilization, for purposes of this discussion it is postulated that vehicle characteristics are more

pertinent to cargo loading utilization, and that the type of service is more pertinent to operational utilization.

4.3.2 OPERATIONAL UTILIZATION

To be utilized operationally a transport vehicle must be capable of departing when called upon with sufficient equipment and supplies to complete its assigned mission. Because of the particular situation, a vehicle may not be able to fulfill this requirement, and the operational utilization will thereby be less than its potential. Factors which affect both the potential utilization, and that which is realized, will be examined.

4.3.2.1 TRANSPORT AIRCRAFT

The two general classifications of transport aircraft service to be considered are military-oriented and commercial-oriented. In military-oriented transport operations, the objective is to operate an aircraft fleet, sufficient in size to meet a specified minimum wartime transport requirement, in the most efficient and economical way; at the same time maintaining the fleet equipment and personnel in a state of readiness.

For commercial operations, the purpose is to operate the minimum number of aircraft required for a given route structure, so as to produce the highest possible revenue. These two basically different objectives have significant effects on utilization figures attained by operators.

Both types of operation are subject to conditions beyond their control which tend to prevent these objectives from being realized. The following sections discuss these factors.

4.3.2.1.1 MILITARY OPERATION

The operation of the Military Air Transport Service (MATS) is used here as an example of military transport aircraft. As a result of their wide experience with transport aircraft, MATS has selected as their annual planning factor a peacetime utilization of 5 hours per day, and 8 hours per day, wartime. The latter factor was used in computing the aircraft fleet size in Sections 4.6.2.1 and 4.6.3.1, and the former for costing purposes in Section 5.

Higher utilizations have been attained and sustained for short periods. As an example Fig. 78

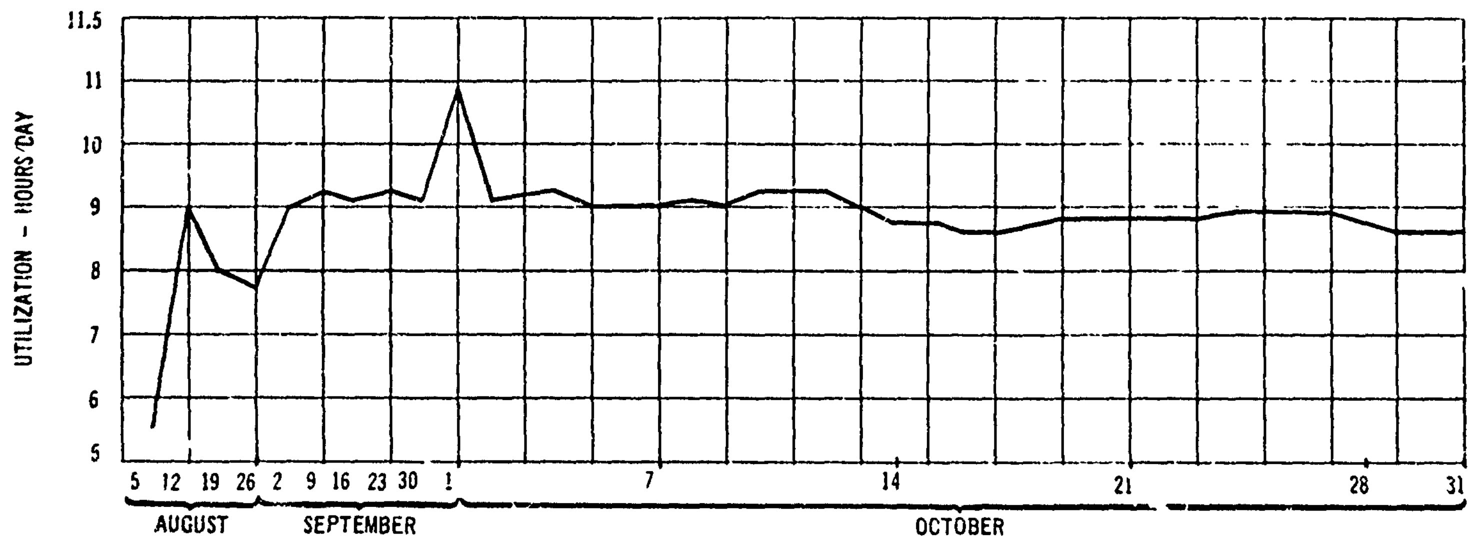


Fig. 78 1948 Berlin Airlift Cumulative Utilization of C-54 Aircraft

shows utilization rates attained by C-54 aircraft during 3 months of the Berlin Airlift in 1948. These side-loading aircraft were called upon to haul unsuitable cargos on short hops in unfavorable weather. Despite these handicaps, the C-54 was able to sustain an approximate 9 hours per day utilization for two months. The first two months of the period show the effects of a surge to high utilization.

Factors which influence operational utilization are listed in Table 9. The most significant factors are perhaps the mission and the maintenance policies.

The size of a military airlift fleet is based on a minimum wartime transport requirement. This fleet is operated in normal peacetime missions, which include a significant amount of training.

Table 9 Operational Utilization Factors

MILITARY AIRCRAFT

1. Missions
2. Routes and Distances
3. Traffic Characteristics
4. Traffic Density
5. Maintenance Facilities
6. Personnel Availability and Training
7. Airplane Characteristics
8. Maintenance Policies
9. Weather
10. Terminal Facilities

The allocation of aircraft to the missions will determine, to a large extent, their operational utilization. Some aircraft, due to scheduling problems, might be inadequate for their assignment, while others would be used only to provide minimum crew proficiency (for which their transport capability would not be used).

OPERATIONAL UTILIZATION METHOD

The following method is an approach to estimating the potential utilization available for short term strategic deployments, based on flight time. The example uses empirical data pertaining to a typical military jet transport. The method may be applied to turboprop and reciprocating engine powered aircraft by applying appropriate experience factors.

This method shows that deployments with long flight legs may have a high utilization while for deployments with short flight lengths, a much lower utilization may be realized.

DEFINITION OF TERMS

Operationally Ready (Ops Ready): A military aircraft is considered Ops Ready when it is capable of flight and has sufficient equipment, supplies and personnel to carry out its assigned mission.

"Other": Non-flying Ops Ready time such as servicing, minor maintenance, testing, loading, taxiing, etc., is not included in Ops Ready times.

Not Operationally Ready - Supply (NORS): This includes all downtime for supply delays.

Not Operationally Ready - Scheduled Maintenance: Included in this category are periodic (PE), hourly post flight (HPO), special and depot inspections and major modifications. The method

presupposes that these inspections are performed on a flight hour basis rather than on calendar time.

Not Operationally Ready-Time Compliance Technical Order (NOR-TCTO): The time spent in conforming to TCTO's is the only time included in this category.

Downtime: This is the sum of all the applicable elements listed above.

Utilization: For purposes of this method, utilization is defined as the number of total flight hours divided by total aircraft-days of the period being considered.

Average Flight Length: This term is computed by dividing the total flight hours, as above, by the number of sorties, departures, or landings, made. If landings are used, only those involving a full stop and shutdown of engines are to be counted.

MAXIMUM POTENTIAL SUSTAINED UTILIZATION FOR ONE FLIGHT LENGTH

Fig. 79 was constructed using time allocation

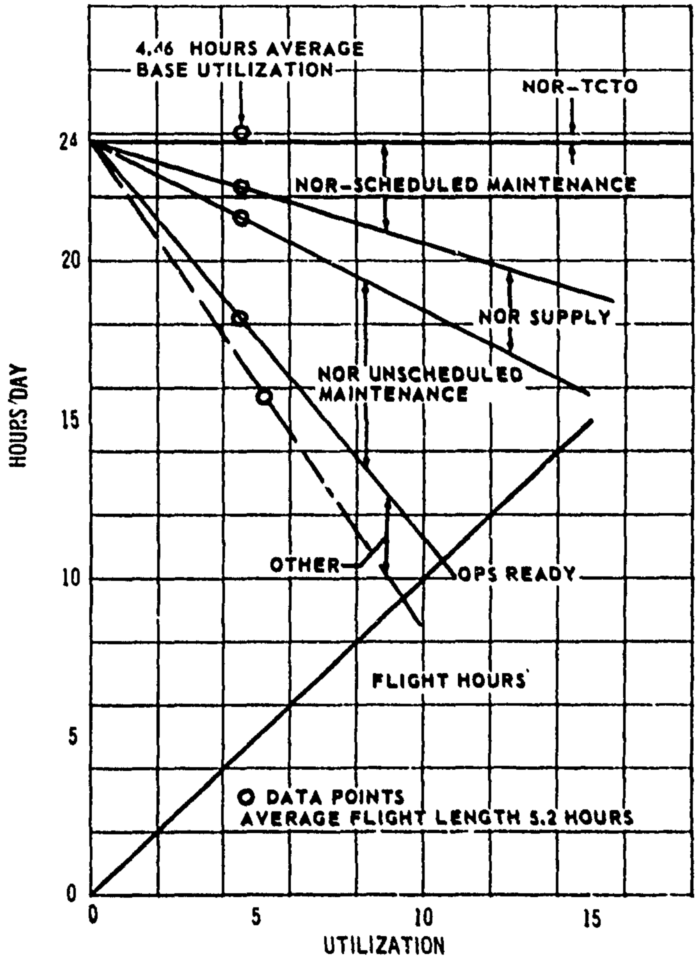


Fig. 79 OPS Ready and Nor Elements Typical Jet Transport

factors for a typical military jet transport, shown below. Straight lines through the data points represent an average flight length of 5.2 hours, since all elements except NOR-TCTO increase proportionally with utilization. TCTO downtime remains constant since it is a function of aircraft design.

Table 10. Daily Time Allocation Typical Military Jet Transports

(BASED ON AN APPROXIMATELY 2 YEARS OF OPERATION)

	FACTOR PERCENT	DAILY TIME HOURS
NOR-TCTO	0.8	0.19
NOR-Sched Maint	6.1	1.46
NOR-Supply	4.2	1.01
NOR-Unsched Maint	12.9	3.10
Operationally Ready	76.0	18.24
TOTALS	100.0	24.00
Operationally Ready "Other" Time:		
Loading, Awaiting Maint., Fueling, Inspections, Unloading, Etc. *		2.00
Taxi Time		.33
TOTAL		2.33
Average Flight Length		5.2
Average Utilization		4.46

* Varies with aircraft, mission, facilities, etc.

Considering also the time required for "other" non-flying Ops Ready elements, it is assumed that total elapsed time for these functions would be, typically, 2.33 hours. On the basis that half of these functions, except taxiing, could be accomplished simultaneously, the total "other" downtime per flight would be 1.33 hours. This time is plotted at 5.2 hours utilization, since it represents one flight of that duration. Since "other" time also varies with the number of flights, a line drawn through the average utilization shows this relationship. Different circumstances, such as in loading, fueling, maintenance techniques, ground support, etc., could cause this item to vary.

Since this plot represents an aircraft day, if an aircraft flew 5 hours in a day its utilization would be 5 hours/day. This is shown by a line drawn at a 45°-angle from the origin. The intersection of this line with the "other" downtime line represents the maximum potential sustained utilization; in this example, approximately 9.4 hours per aircraft day, at an average flight length of 5.2 hours.

MAXIMUM POTENTIAL UTILIZATION FOR VARYING FLIGHT LENGTHS

To determine this utilization for varying flight lengths, the factors used above may be adjusted based on the following assumptions:

NOR-TCTO: Assumed to remain constant, as above.

NOR-Scheduled Maintenance: Varies with flight length, since it is based on flight hours.

NOR-Supply and Unscheduled Maintenance: Assumed to vary proportionally with the number of failures per flight. For a typical jet transport, the curve labelled "Airplane" in Fig. 80 is used.

Other: Assumed to remain constant.

Fig. 81 is a plot of cumulative downtime per flight per element versus flight length, using the factors of the preceding example and the above assumptions. This information permits Fig. 81b to be drawn by superimposing a 45° line, representing flight time per flight, on the downtime relationships of Fig. 81a.

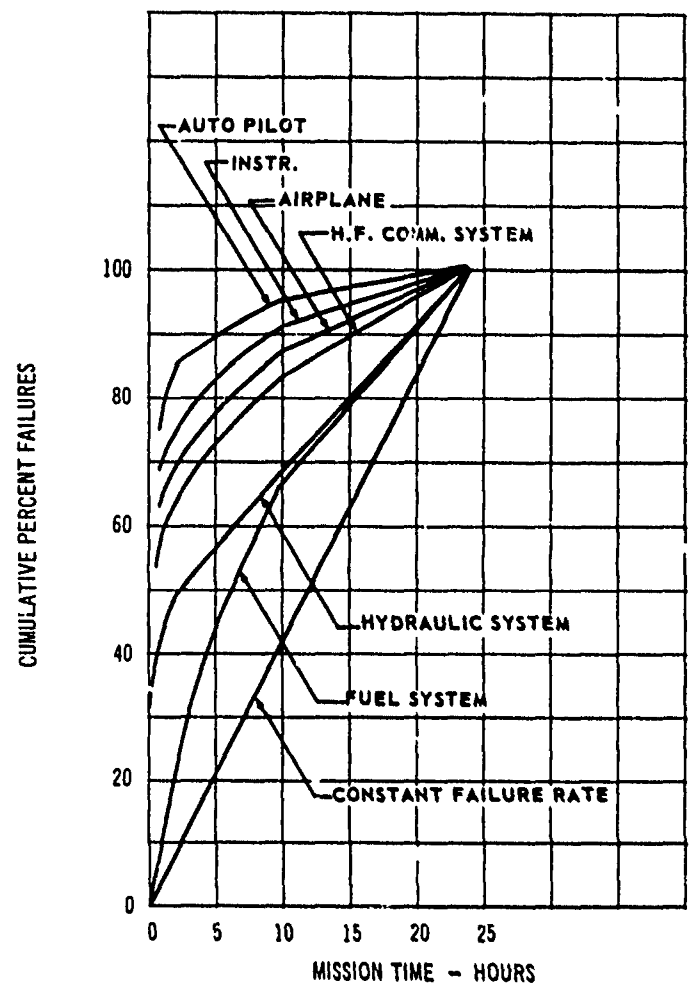


Fig. 80 Cumulative Failure Rate For Various Mission Times

Fig. 81c is constructed by drawing diagonal lines in Fig. 81b which extend from the origin through the intersection of downtime per flight line to the desired flight time. The intersection of the flight time per flight line and these diagonal lines permits average utilization to be read on the right hand scale. These readings are plotted versus flight length in Fig. 81c to show maximum average potential utilization vs. flight length. For example, if a 5 hour flight length is selected, a proportioning line drawn from the origin through the downtime per flight line for a 5 hour flight intersecting the flight time per flight line, permits reading a maximum potential sustained utilization of 10 hours/day on the right hand scale of Fig. 81b. Fig. 81c allows this to be read directly. Fig. 81a is included to permit, if required, the elimination of certain downtime elements such as TCTO and NOR-Scheduled Maintenance should emergency conditions require. If such were the case, through use of this method a maximum potential sustained utilization of 11.9 hours per day at 5 hours flight length is theoretically possible.

The data used in Figs. 79 through 81 were based

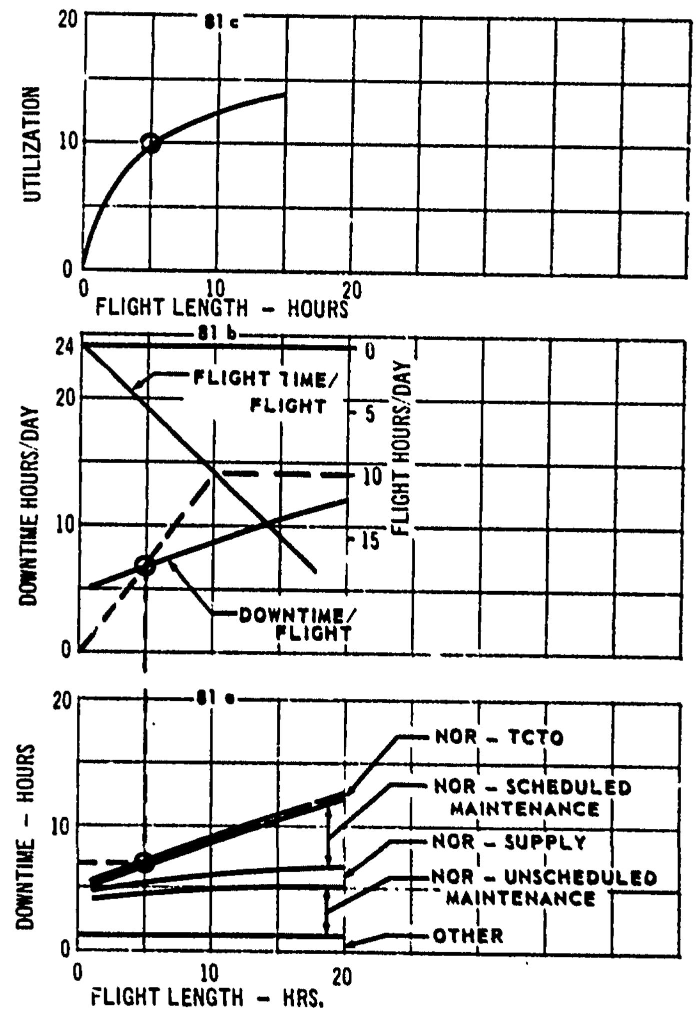


Fig. 81 Method of Developing Maximum Average Utilization Curves

on peacetime operations. Fig. 82 shows how emergency or wartime planning can be used to adjust the elements of downtime mentioned above, and in addition, to account for such contingencies as weather, user policy, operations, etc., which were not included in Fig. 81. This is believed to be a reasonable assessment of the potential available to the military. The dotted line in Fig. 82 represents a composite of airline data, including all delays, for three years of operation.

4.3.2.1.2 COMMERCIAL OPERATION

Higher utilization rates are attained in commercial airline service than in military service. The basic reasons for this can be attributed to their different types of routes, cargos, policies, and to the lower maintenance skill levels available in the military organization.

Commercial utilization of passenger aircraft is most significantly influenced by route structure and passenger convenience scheduling. Other factors which apply are listed in Table 11.

The highest potential utilization is attained

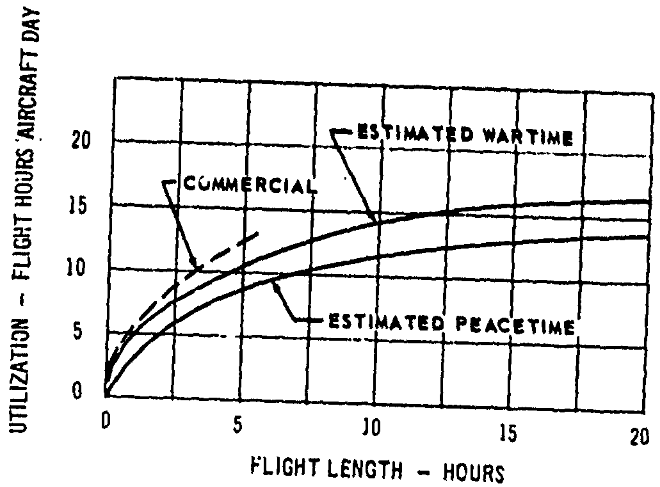


Fig. 82 Projected From Jet Transport Maximum Sustained Utilization

when the route structure and the passenger density allow the airplane to fly fully loaded during the normal traveling period between 7 A. M. and 12 Midnight. Maintenance work is then scheduled for the remaining 7 hours, insofar as is possible. In general, airline maintenance is accomplished on a continuous basis, using if necessary, three working shifts - 24 hours per day - until the work is completed.

The revenue utilization for some twelve airlines flying various types of aircraft during a five

Table 11 Operational Utilization Factors – Commercial Aircraft

1. Traffic Density
2. Routes and Distances
3. Schedule Protection
4. Connecting Flight Requirements
5. Departure/Arrival Times
6. Maintenance Facilities
7. Personnel Availability
8. Airplane Characteristics
9. Maintenance Policies
10. Weather
11. Terminal Facilities

year period from 1957-1961 is shown graphically in Fig. 83. Statistics for this plot were obtained from figures published by the Air Transport Association of America. This period was significant to the airline industry in that it marked the transition from reciprocating engine powered aircraft to turbine-powered aircraft, both jet and turboprop. It is believed that the downward trend in reciprocating engine powered aircraft utilization is a result of their being replaced by the turbine craft on the longer routes. This tended to increase the turbine aircraft utilization and decrease the utilization for the piston engine aircraft.

Commercial cargo aircraft have the potential of exceeding passenger utilization, since they, presumably, can be scheduled on a 24 hour a day basis. For cargo operations, therefore, maintenance becomes a more limiting factor than for passenger operations.

4.3.2.2 TRANSPORT SHIPS

The operational utilization of a ship is divided into two general categories: ship design and operating characteristics, and situation and circumstance factors.

SHIP DESIGN AND OPERATING CHARACTERISTICS

The ability to obtain high transport ship utilization, from an operational standpoint, depends on the type of vessel and how it is operated in relation to its capabilities. Such vessels may be divided into classifications of cargo, combination, and passenger, depending on the number of passengers carried.

New United States vessels, which are constructed under government subsidy, are designed for the capability to sustain 20 knot speed, for possible use in a military emergency. This high sea speed tends to reduce utilization, by decreasing

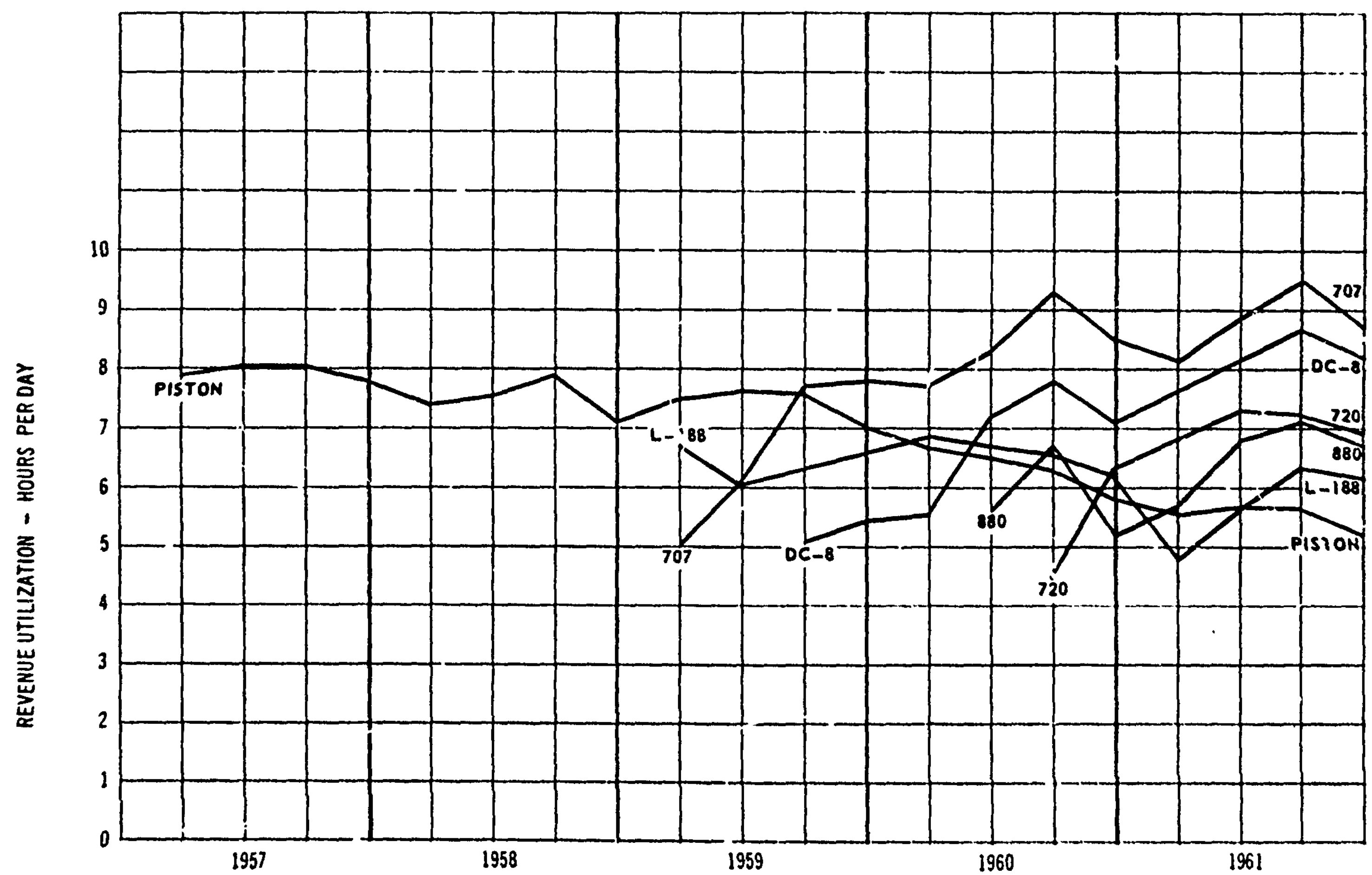


Fig. 83 Revenue Utilization – All Domestic Trunks

the amount of time spent at sea in relation to the time spent in port. Port time is the time which a ship spends loading or unloading, undergoing maintenance, awaiting repairs, or awaiting cargo.

Since port time has such an adverse influence on operational utilization, both ship designers and operators are particularly cognizant of factors which affect it. The addition of more hatches, quick-removal hatch covers, faster Burtoning gear, accommodations for containers, and special designs for vehicular loads all tend to increase operational utilization. The effect of speed on productivity of various types of cargo vessels is illustrated in Fig. 84. The space factor (S.F.) is explained in Section 4.3.2.3.

SITUATION AND CIRCUMSTANCE FACTORS

Since a ship is normally producing revenue only while it is at sea, to realize maximum capability port time must be reduced to its practical minimum. For a commercial cargo ship, it may be necessary to strike a compromise between operational utilization and space utilization for reasons of economy.

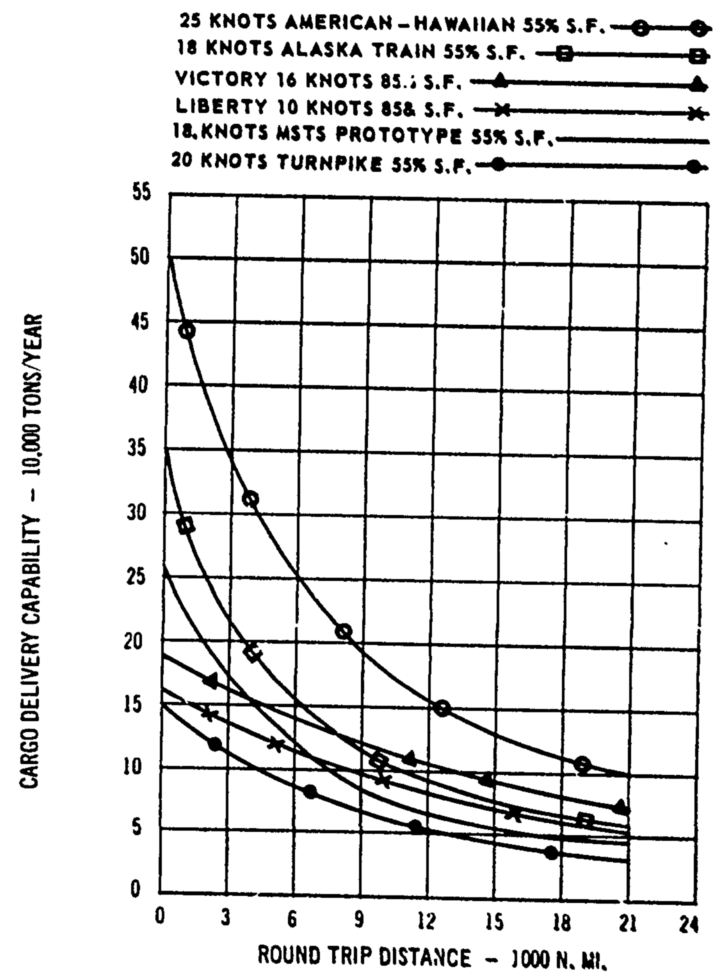


Fig. 84 Yearly Cargo Delivery Capabilities Of Various Ships For Round Trip Distances

Loading and unloading times are influenced by such factors as dockside cargo handling gear, stevedoring rules, and type(s) of cargo carried.

Repair, maintenance, and reprovisioning are normally accomplished concurrently with load/unload operations. However, insurance underwriters require commercial vessels to undergo a drydocking at approximately one year intervals. These operations require from seven to ten days to complete, during which time scraping, painting, inspection, and major overhaul are performed. For normal ship operation, annual drydocking is the only completely non-operational time. Exceptions do occur as a result of unforeseen or unpredictable events such as accident, weather, or major machinery breakdown.

The type of ports, their number, and distance between them are also of significance in determining operational utilization. The effect of distance between ports is also illustrated in Fig. 84.

4.3.3 LOADING CAPABILITY UTILIZATION

Loading capability utilization of transport vehicles refers to the effective use of available weight and space. Influential factors include, but are not limited to, cargo characteristics, cargo compartment characteristics, performance of the transport vehicle, facilities, seasons, policies, politics, routes and distances, schedules, availability of vehicles and/or cargo, economics, and safety.

4.3.3.1 TRANSPORT AIRCRAFT

The loading efficiency of transport aircraft is largely a compromise between available cargo and available aircraft space and payload.

4.3.3.1.1 MILITARY OPERATION

Past transport designs have emphasized payload capability, an ineffective criterion for bulky, low density cargo items. As a result, the present day military aircraft have limited capability for carrying such Army equipment. The loading utilization is shown in Table 12 for four current aircraft and four typical military loads.

4.3.3.1.2 COMMERCIAL OPERATION

Passenger Service: Fig. 85 shows revenue pass-

Table 12 Aircraft Loading Efficiency

	AIRBORNE DIVISION	INFANTRY DIVISION	MECHANIZED DIVISION	ARMORED DIVISION
AVERAGE CARGO FLOOR LOADING LBS/SQ FT	73.6	104.5	117.5	140.1
	APPROXIMATE PERCENT AIRLIFTABLE BY WEIGHT			
AIRCRAFT TYPE (ALLOWABLE CABIN LOAD, LBS)				
C-124 (39,200)	99	70	69	60
C-130 (44,500)	95	64	64	56
C-133 (77,500)	100	74	72	61
C-141 (89,300)	96	71	64	56

enger load factors for all U. S. domestic trunk carriers over the five year period during which jets were being introduced. The immediate popularity of jets is apparent; however, load factors soon dropped as more of these very productive aircraft were placed into service, and the passenger traffic was unable to increase accordingly. It is interesting to note that the load factors for piston engined aircraft and turboprop dropped from roughly 60 percent to 52 percent over this pe iod.

Cargo Service: Whereas commercial aircraft are space limited in passenger service, cargo service tends toward a weight limited condition although many cargo loads are also space limited. The jets being larger should have a higher weight utilization in cargo use.

Fig. 86 illustrates trends in cargo load factor and revenue productivity as reported by the Air Transport Association. The period subsequent to 1960 shows the same load factor tendencies as were experienced in passenger service a year or so earlier (Fig. 83).

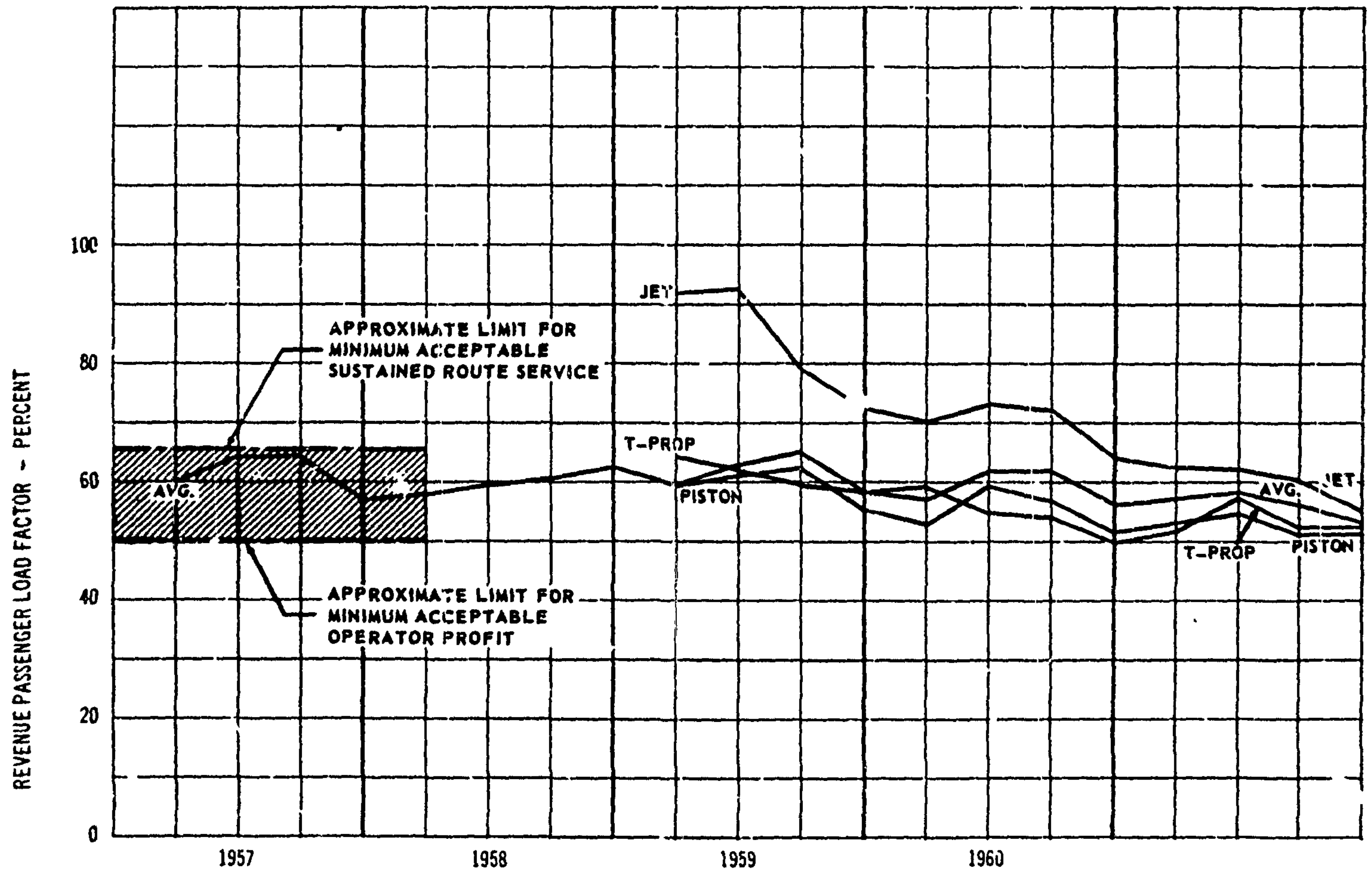


Fig. 85 Revenue Passenger Load Factors

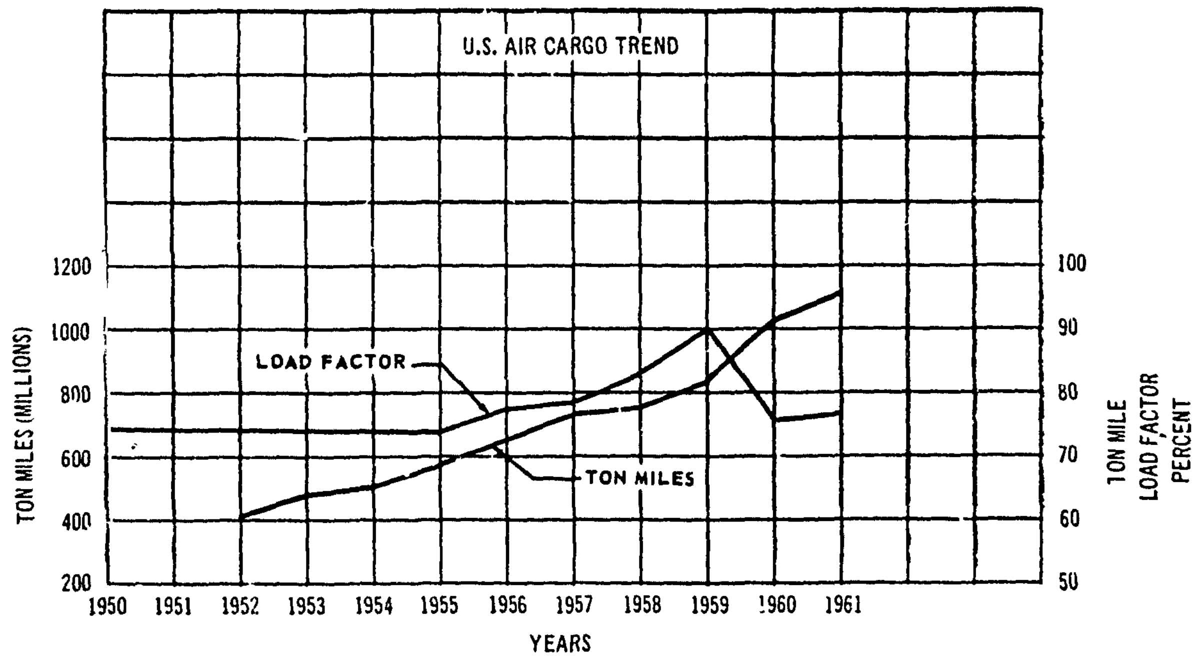


Fig. 86 Cargo Load Factor and Revenue Productivity

Commercial cargo operators are continually incorporating new ideas on loading, many of which were pioneered by the military. Perhaps the most notable such innovation is the 463-L system, which can be instrumental in increasing operational utilization.

4.3.3.2 TRANSPORT SHIPS

Since most of the remarks applying to loading capability of aircraft also apply in some degree to ships, this discussion will be limited to those items which are peculiar to ships.

Ships, like aircraft, are very dependent on correct weight distribution. In the case of ships, however, there is an additional complicating factor because they must be correctly loaded vertically as well as in the normal longitudinal and lateral directions. This three dimensional distribution, coupled with the wide variety of cargos which a ship may carry, poses a significant planning problem for the load master.

In order to operate safely and efficiently, a ship must be loaded so that it is "full and down" -- "full" in the sense that a maximum of the available space has been used, and "down" meaning carrying a sufficient amount of weight to assure stability and a comfortable ride.

Variations in the type and character of cargo do not always permit a ship to operate full. Each commodity has a stowage factor which represents the cubic feet of space occupied by one long ton (2240 pounds) of that material. When a vessel is loaded, it may not be able to accommodate cargo in the entire space available. There is often additional space lost between individual items of cargo. This loss is referred to as "broken-stowage". This is at a minimum for bulk cargos such as grain or liquids, and is at its maximum for irregularly shaped items like vehicles, which cannot be easily stacked. The amount of space actually used, divided by the space available for use, gives an overall space factor (S.F.) for the ship. Such representative values for various types of ships were shown in Section 4.3.2.2, Fig. 84.

Efficient cargo loading may also be influenced by the design and construction features embodied in a ship. The allocation of space to living and working areas, machinery, fuel storage, and structural members, as well as the locations of these items, governs to a large extent the amount of cargo capacity and how it may be utilized. The number and size of hatches, winches, and other cargo handling gear are also factors. Specialized developments in the field of maritime transportation are the roll-on/roll-off (RO/RO) vessels, containerships and trailerships. These ships are designed for rapid handling of particular types of cargo or cargo packaging, and are significant from a loading capability standpoint in that they often sacri-

fice good space utilization for rapidity and ease of loading/unloading (See Section 4.3.2.2).

A cargo ship suitable for military deployment should have the characteristics shown in Table 13.

Table 13 Cargo Ship Requirements For Maximum Military Deployment Utility

1. **Minimum of two cargo decks for wheeled or tracked vehicles.**
2. **Sufficient deck heights to accommodate military cargo.**
3. **Adequate deck strength to support heavy tanks and loaded vehicles.**
4. **Facilities to permit ready maneuvering of cargo on each deck, and rapid transfer of cargo between decks.**
5. **Independence of dockside facilities for loading/unloading military cargo.**

4.4 USEFUL LIFE

4.4.1 GENERAL

The useful life of a transport vehicle can be measured in either of two ways - structurally or economically. Both factors depend heavily on when, where, and how the vehicle is operated, and are mutually related. The vehicle design is governed by principles of economics in the amount of refinement incorporated, in quality of materials and in the projected useful life. Structural considerations are intertwined with economics by governing the frequency and severity of repair, replacement, and maintenance required to keep the vehicle operational.

4.4.2 STRUCTURAL LIFE

The structural life of a transport vehicle is defined as the time period during which the vehicle is operationally useful, taking due account of the design mission and safety standards. It is strongly dependent on many of the elements of Section 4.2, Reliability; Section 4.3, Utilization; and Section 4.5, Environment.

4.4.2.1 TRANSPORT AIRCRAFT

4.4.2.1.1 DISCUSSION

Aircraft structural life is a complex function of economics which is directly dependent on detail design, aircraft performance, and structural maintenance. The requirement to inspect, repair, or replace components after each flight

to assure continued reliability may be restrictive and lead to aircraft replacement.

There are no precise means of determining aircraft structural life; rather, it is a question of how much maintenance is acceptable to the operator. For example, such aircraft as the Ford Tri-Motor, the DC-3, the DC-4, the C-46 and other similar types have been either retired from or continued in service on the basis of economics rather than strictly a structural life limit.

Contributing to the structural maintenance requirements are factors of use such as fatigue, corrosion (chemical, galvanic, stress, fretting), embrittlement, thermal stresses and creep. Each of these phenomena are influenced by detail design, material selection, manufacturing techniques and operating procedures. Of all the factors contributing to structural maintenance requirements, fatigue has been the major focal point. The following paragraphs describe in more detail some of the features which influence structural life or structural reliability as affected by fatigue considerations.

4.4.2.1.2 FATIGUE AS A LIMITING FACTOR

Table 14 gives typical fatigue-free service life goals for three classes of commercial transport aircraft. Actual life is a combination of environment loads and number of flights. Military goals may be identified in a source like Ref. 34. Generally speaking, the fatigue-free life requirement of military aircraft is less than that of commercial airplanes.

Table 14 Typical Fatigue – Free Service Life Goal

COMMERCIAL TRANSPORT AIRCRAFT

USAGE	TIME
Medium to Long Range	30,000 - 50,000 flight hours
Short to Medium Range	20,000 - 30,000 flight hours
Short Range	15,000 - 20,000 flight hours

The many items affecting fatigue performance can be classified into three categories. These are detail design, natural environment and self-induced environment. Only one of these three categories, detail design, is within the direct control of the aircraft designer.

The elements of detail design considerations can be summed up briefly as follows:

- Joint Configuration: The structural geometry, which defines load path and local stress concentrations is most significant in defining fatigue performance. Laboratory tests have shown joints of similar static strength to differ in fatigue characteristics from 10 to 100 times or more.

- Fasteners: Both the type and arrangement of fasteners in a joint are important to fatigue performance. Use of increasingly stronger fastener alloys to join structural members causes effects detrimental to fatigue life. Generally, this increased fastener strength means greater load transfer, reduced diameters and increased flexibility with its tendency to localize (i.e., increase) load transfer effects and thereby, shorten fatigue life. Interference fits between holes and fasteners are generally beneficial. Fatigue performance of structures with clearance-fit fasteners may be as little as a third to a tenth that of the interference-fit fasteners.

- Processes and Manufacturing Techniques: Fatigue performance is vitally affected by process and manufacturing techniques. Examples of these are: decarburization, plating or cleaning; residual stresses resulting from processes or installation techniques; surface treatment, such as machining effects, protective finish, etc.; or process effects such as forged or cast surfaces, cold working and shot peening.

- Material: The selection of material, its grain direction and form, (i.e., wrought, cast, and forged or rolled) are all significant factors in fatigue performance. Notch sensitivity, crack propagation, and residual strength capabilities are important in providing structural safety under fatigue conditions.

- Fretting: Structures connected by fasteners generally experience microscopic relative motion under variable loads. By such relative motion, faying surfaces are subject to fretting corrosion with a consequent degradation of fatigue performance.

- Stress Level: Stress level is an important key to fatigue performance. Increased stress levels may multiply the deleterious effects of detail features, noted above, as well as being significant in their own right. For example, halving the operating stress levels can increase the fatigue life of a structure by a factor of 10 or more.

Physical environment effects, which may in actual use differ from that estimated during the design stage, include:

- Corrosion: The various forms of corrosion are all detrimental to fatigue performance. Pitting corrosion has the same effect on the fatigue performance of a material, particularly the aluminum alloys, as does an open hole. Intergranular types of corrosion will more nearly reflect the severe notch effects of a fatigue crack itself.

- Temperature: The more significant effect of temperature is on the creep and rupture characteristics of a material. These, in turn, can create local stress readjustments that may be significant.

Another general area affecting fatigue performance is variable load environment. Some of these elements are:

- Gusts: Turbulence in the atmosphere is probably the most significant fatigue element of the variable load environment. Using the average of all gust data, a difference of over 100:1 can be found between the 5,000 foot altitude and altitudes of 30,000 to 40,000 feet. Gust experience can only be defined in a statistical sense. Fig. 87 reflects a typical variation in gust occurence due to altitude.

- Flight Length: Flight length or profile is a significant factor in the fatigue life evaluation of transport aircraft. Short flights are significant not only in relation to flight structure (wings, pressurized cabins, etc.) but also in their effects on landing gears. Fig. 88 illustrates the variation in fatigue damage, in terms of flights and hours, for structure predominantly

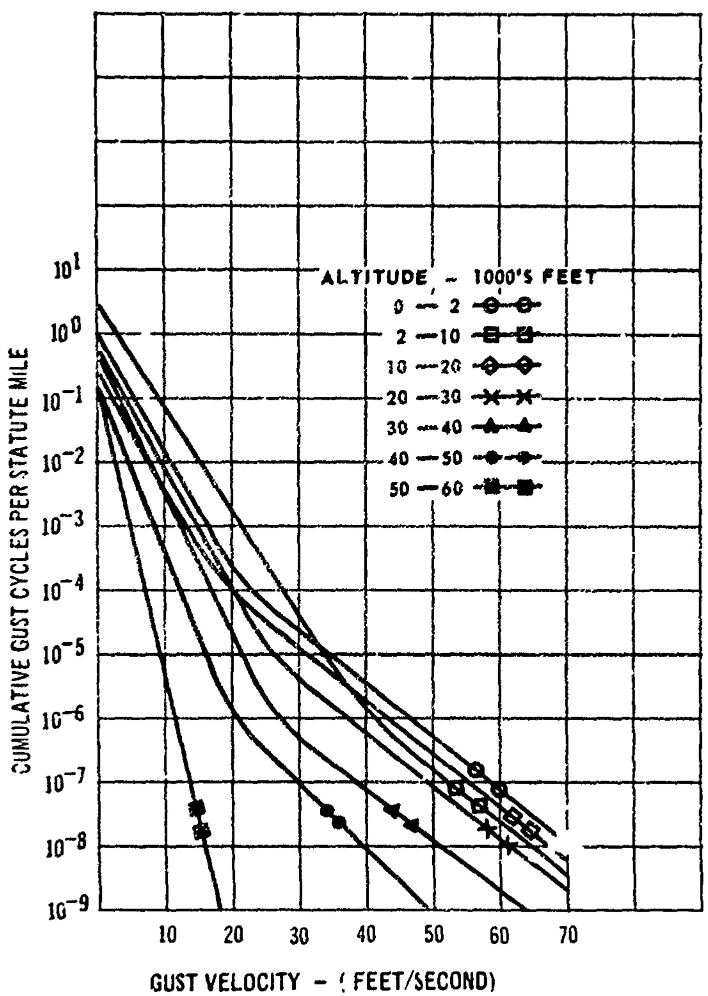


Fig. 87 Effect of Altitude on Gust Load Environment

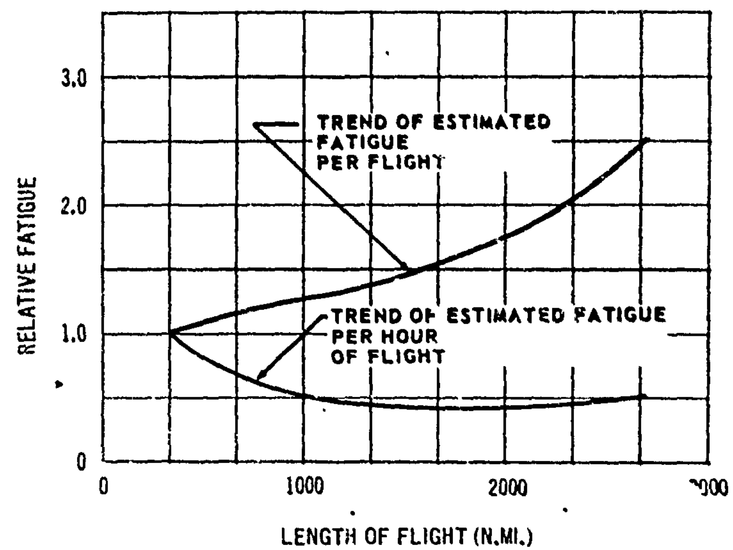


Fig. 88 Estimated Fatigue Variation With Flight Length

dependent upon flight profile.

- Configuration: Such factors as aspect ratio, wing fuel distribution, wing mass distribution due to engines or stores, wing sweep, cabin pressurization, and center of gravity position all have their effect on fatigue performance. The degree and trend is dependent upon the specific configuration. For example, wing sweep, with the resultant re-

duction in the slope of the lift curve as the sweep increases, causes a reduced response to turbulence. Fig. 89 illustrates the relative fatigue performance of a wing structure as sweep is varied.

Two "design against fatigue" concepts have evolved. These are the "safe life" concept and the "fail safe" concept. The first concept does not tolerate the appearance of fatigue failures. The fail-safe concept strives not only to avoid the appearance of fatigue damage but, should it occur, provides a structural capability to contain the damage until detected and repaired. With the safe-life concept, structure must be retired at an established time. The fail-safe structure has the same goals as a safe-life structure and also has the additional capability for extension of the goals or even meeting the goals in spite of unpredicted or premature fatigue damage. Only the amount of maintenance, not safety or reliability, forms the limit to the potential service life of the fail-safe structure.

The fatigue performance of safe-life structure and fail-safe structure is illustrated, in Fig. 90, in simplified form.

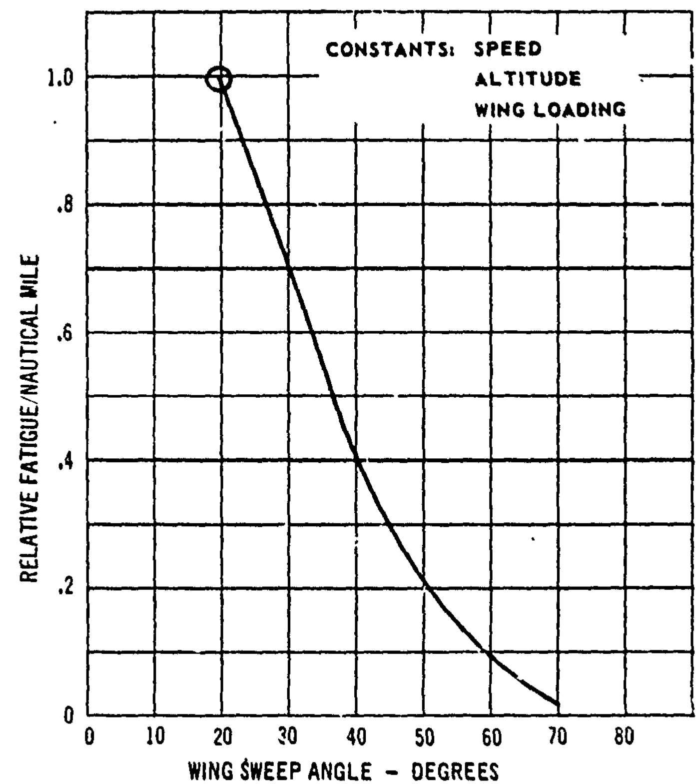


Fig. 89 Approximate Trend of Estimated Wing Fatigue With Wing Sweep Angle

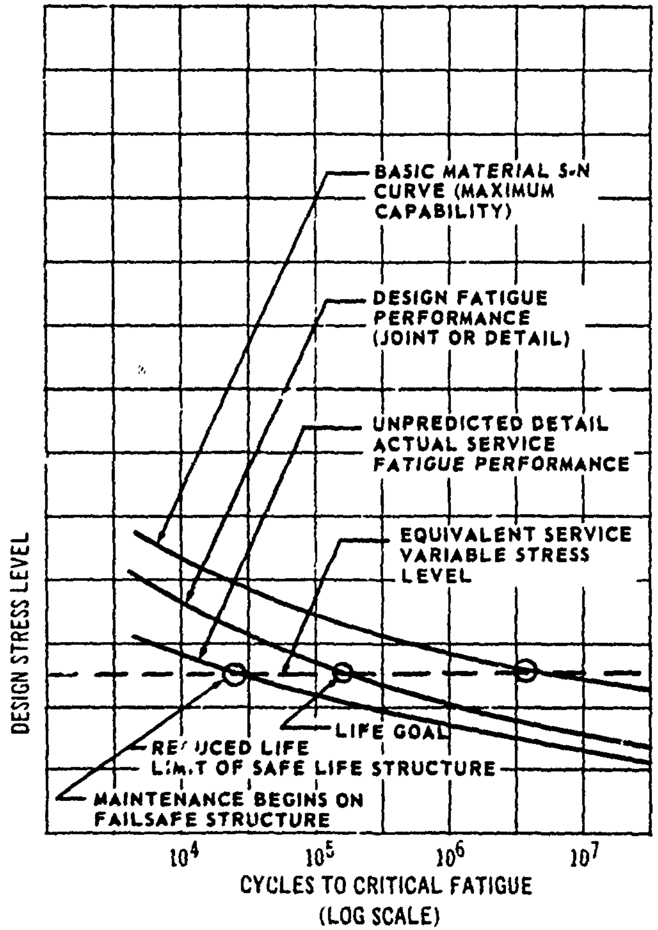


Fig. 90 Fatigue Performance Goals and Limits

4.4.2.2 TRANSPORT SHIP

Because of the dominant role played by the marine insurance underwriters in establishing design and construction criteria, operating practices, and maintenance requirements, structural longevity of ships is well assured. Moreover, high reliability requirements for ships and the techniques for their realization are less complex than those for aircraft and are more easily attained.

The major obstacle to long structural life of ships is corrosion, either from internal sources or from the operating environment. However, with normal maintenance these problems are successfully circumvented.

In view of these factors, it is concluded that transport ships have an unlimited potential structural life. The major determinants of ship life may be technological considerations as in the case of aircraft, or legislation determined by national policy.

4.4.3 ECONOMIC LIFE

In all but wartime or emergency operations, the economics of transport vehicle operation are a significant and underlying factor in the consideration of parameters covered in Section 4.0. A commercial vehicle should be capable of attracting revenue in excess of its expenses, thereby affording an opportunity for profit. A military vehicle should provide the capability to perform its assigned mission at minimum total cost.

4.4.3.1 TRANSPORT AIRCRAFT

The major factor in the economic life of transport aircraft is technological obsolescence.

For commercial vehicles, this creates a situation whereby an aircraft may no longer return maximum profit in the service for which it was designed. This has occurred when some aircraft were comparatively new in terms of use and structural life. The situation is generally determined by competition. It happened to reciprocating engine aircraft when the jets were introduced. The technological spiral may perhaps catch the subsonic passenger jets when supersonic transports become operational. To counter these economic trends, operators tend to convert the replaced aircraft to service where technological obsolescence is not so important. This, in part, explains the upswing of air cargo service. At the present time, the economic life of a commercial jet aircraft is considered to be from 12 to 14 years, depending on the airline. None of these jet aircraft has reached this age yet and it remains to be seen if they will be used for this full time period.

A similar technological evolution is taking place in the military as the older transport aircraft are being phased out in favor of more productive, newer models. The trend to the newer aircraft is a result not only of advancing technology, but of the changing requirements imposed on airlift capability by the worldwide threat of limited warfare. The current political climate requires aircraft of much larger payload capability than that of piston engine aircraft. This fact contributes to hastening their replacement.

Military transport aircraft are currently considered to have an economic first-line life of approximately 10 years.

4.4.3.2 TRANSPORT SHIPS

National policy dictates that the United States shall have a modern and capable merchant marine which can be employed in the event of international crisis. There are three major economic factors which tend to prevent realization of this goal. One is the almost indefinite life of a well built ship. Second, is the strength and influence of the maritime unions and third is foreign competition. To counteract these, the government provides necessary incentives in the form of subsidy payments, enforced retirement of vessels after a specified period of service, and by passing protective legislation. The economic life of a U.S. flag vessel is artificial; it is controlled by national policy.

The United States transport ship fleet is composed of approximately 1000 major ships. This number is distributed among the subsidized commercial operators, unsubsidized fleet - including coastwise trade and tankers, Military Sea Transportation Service (MSTS) nucleus fleet, and tramp steamers.

Realizing the importance of a healthy shipbuilding industry and modern maritime capability, the government insures these assets by the Maritime Administration (MARAD). MARAD is empowered to enter into contracts with domestic ship operators whereby a subsidy is paid in return for the authority to dictate certain operating policies and to determine ship economic life.

The subsidies, which are billed to MARAD at the conclusion of each voyage, include partial reimbursement for varying percentages of costs incurred by the operator for such items as wages, repairs, and stores, in order to equalize them with those of foreign operators.

In return for these subsidy payments, the operator must comply with MARAD regulations governing the number of voyages, ports of call, cargos carried, labor practices, etc., and must agree to retire his ships at the end of a specified period. Prior to 1960, this economic life was

20 years; however, Public Law 86-518 enacted in that year increased the life to 25 years for all but World War II ships, which remained as before. During the economic lifetime of a subsidized vessel, payments are made by the operator to an amortization fund to replace the vessel when it is retired. The design specifications for the replacement are normally chosen from MARAD files, and construction of the new vessel is completed in a domestic shipyard which is also under MARAD subsidy.

The government-owned MSTS nucleus fleet provides a basis for mobilization in the event of national emergency as well as a small fleet which is exclusively in government service. This fleet is capable of operating at a profit, based on industrial funding (the payment to a government agency a rate comparable to that normally paid a commercial operator).

Since MSTS is non-profit, the excess of revenue, if any, is returned to the using agencies in the form of lower subsequent rates.

The largest U.S. maritime fleet is actually that owned by MARAD. This consists primarily of World War II vessels which have been decommissioned and placed into dead storage as a possible national defense measure.

These vessels are maintained so as to require a minimum of time to outfit if they should be needed. Ships in the dead fleet may be retained, scrapped, or sold, at the discretion of MARAD.

Effectively the economic life of these stored ships is completed on their entering storage. The option to change this condition is exercised only should national interest require it.

4.5. OPERATING ENVIRONMENT

The environment in which a transport vehicle operates has a significant effect on its reliability, utilization and useful life. It imposes a constant and often unpredictable influence on the vehicle throughout its span of use. Environment may be divided into natural environment and induced environment in order to discuss its effects. Each element is so interrelated with

the others and with other aspects of operating criteria that only a qualitative discussion is possible.

4.5.1 TRANSPORT AIRCRAFT NATURAL ENVIRONMENT

Table 15, below, lists major environmental influences for whose extremes aircraft must be designed, and within which they are operated. The right-hand column shows some aircraft characteristics which may be required because of these influences. These considerations may impose restrictions on the operating efficiency and economy of aircraft or may add weight and complexity and must, therefore, be evaluated in the light of their effects on reliability, utilization, and useful life.

The following paragraphs discuss the major impact of these factors on transport aircraft design and performance.

- Pressurization: In order that aircraft may fly at altitudes which provide greatest efficiency, it is desirable that at least the crew space be pressurized. For aircraft

Table 15 Natural Environment

	FACTOR	AIRCRAFT DESIGN CONSIDERATION
Geography	Terrain	Pressurization
	Soil	Landing Gear Adequacy
	Location	Self-sufficiency
	Vegetation	Takeoff and Landing Capability
Climate and Weather	Humidity	Ventilation
	Temperature	Air-conditioning
	Winds	Powerplant Efficiency
	Gusts	Structural Criteria
	Rain	Communications
	Fog	Navigation Aids
	Snow and Ice	De-Icing/Anti-Icing
	Dust	Surface Protection

which transport personnel, the entire cabin area is pressurized. .is requirement often dictates a circular fuselage cross-section and may impose a structural weight penalty.

- Landing Gear Adequacy: The potential limited warfare situations which prevail throughout the world have emphasized the importance of being able to deliver large quantities of military equipment into relatively unsophisticated airfields existing in underdeveloped areas. This implies the ability to withstand severe landing conditions with heavy loads,

and the capability to provide adequate flotation for the aircraft on surfaces with low load-bearing characteristics.

- Self-Sufficiency: For both military and commercial aircraft operating into relatively unimproved airfields, it is vital that they be capable of providing a high degree of self-contained equipment. This frees them from dependence on the variety of ground support equipment such as starting units, generators, air conditioning trucks, stairs, and cargo handling gear normally provided at the more highly developed air terminals.

- Takeoff and Landing Capability: The same reasons that self-sufficiency and landing gear adequacy are important also influence the requirement for high power, high lift, and deceleration devices to allow operation into and out of short airfields, particularly when these are at high altitude, hot day conditions.

- Ventilation: This is essential when conditions of high humidity and fluctuating temperatures cause condensation on interior surfaces.

- Air Conditioning: Aircraft air conditioning units must be adequate to cope with requirements to heat the inhabited areas of the fuselage when the outside air temperature is as low as -65°F, and to cool it from external temperatures as high as 120°F.

- Powerplant Efficiency: The effects of temperature, humidity, barometric pressure, icing and foreign object ingestion on powerplants are well known. All contribute to the complexity of the installations and due to this complexity influence operating efficiency.

- Structural Criteria: The effect of gusts on the fatigue life of transport aircraft structure is discussed in Section 4.4.2.1.2.

- Communications and Navigation Aids: These electronic devices permit transport aircraft to operate more effectively within the existing natural environment by providing use-

ful information on conditions both before and during flight. Radar is particularly useful in extending the visual horizon, and by replacing it when conditions require.

- De- and Anti-Icing: Since transport aircraft often find themselves operating in icing conditions, provisions are made to prevent or remove the formation and accumulation of ice on the structure.

- Surface Protection: The effects of weather elements on the surfaces of aircraft may have a significant bearing on maintenance requirements as discussed in Section 4.4.2. Oxidation, corrosion, and abrasion occur under certain conditions of exposure.

A few of the sometimes drastic, often subtle influences of natural environment on the design, construction, and operation of transport aircraft have been outlined. By wise use of materials, processes, and techniques, the adverse effects of these influences are, in practice, minimized.

Induced Environment

Induced environment refers to the self-produced effects of design features or operating characteristics discussed in the foregoing section, plus such other elements under the relative influence of control of the operator as are shown in Table 16:

Table 16 Induced Environment Factors

Airport Facilities
Air Traffic Control
Operating Policies
Economic Situation
Mission

The design and operation of aircraft will, in themselves, establish ambient conditions such as temperature and pressure, stress and fatigue, fumes and odors, and corrosion and wear, all of which are relatively independent of natural environment. The major source of these effects is the powerplant, which in addition to the loads imposed by its weight, also generates torque, thrust, heat, and vibration.

The airfield environment is particularly signifi-

cant and may be defined in terms of the number, length, and strength of runways. Fig. 91 gives the free world airfield distribution in terms of numbers of runways and their length. This shows, for example, that an aircraft requiring a runway length of 5000 feet could have a greater operational flexibility in the United States than it would in either Western Europe or Southeast Asia. The potential increases as the required runway decreases below 5000 feet, so that at 2000 feet the available U.S. runways are over 5 times as plentiful as those in Europe. Airports also contribute to the induced environment through the facilities they provide for loading, servicing, storing, and maintaining aircraft.

Navigation and traffic control installations influence utilization of aircraft by permitting safe operation at night, in bad weather, and in areas of heavy air traffic. These facilities include lights and visual beacons, radio navigation aids, radar, voice communication, air traffic control centers, and instrument landing systems. The shorter runways depicted in Fig. 91 tend to have available fewer of these facilities.

4.5.2 TRANSPORT SHIP

Although the same basic environmental factors discussed for aircraft apply also to ships, the influence of these factors is often quite different. This section is intended to show both the similarities and differences.

Natural Environment

Climate and weather are accepted operational considerations for both airplanes and ships; however, the general approach in the maritime industry is to operate despite bad weather, while aircraft operators try to avoid such weather when practical. Once a voyage has been initiated, the ship does not usually try to run from heavy going as an aircraft might, nor does it have significant capability to do this. Climate may be said to have very little influence on marine operations, except in certain special cases such as in areas where persistent fog or ice present a seasonal hazard. However, climate may have a pronounced effect on the efficiency of operating personnel.

With ships, winds are not of great significance except as they affect the speed which may be

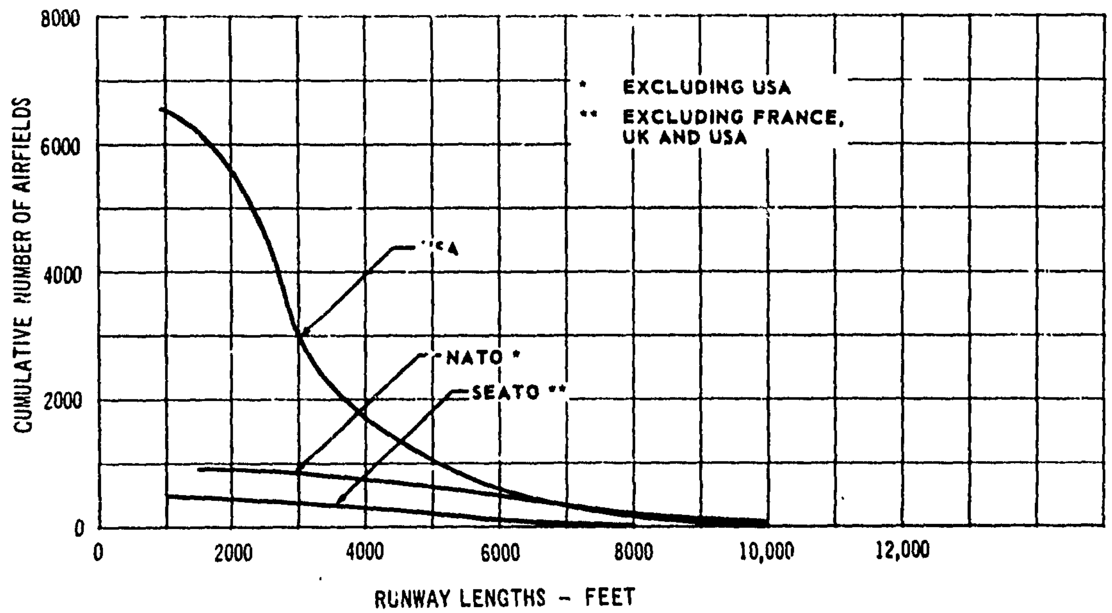


Fig. 91 Free World Airfield Distribution

maintained. Fig. 92 shows the approximate speed that a VC2-AP3 vessel can make, depending on the size and direction of wave action. As expected, speed decreases as wave height increases, and as waves move contrary to the direction of the ship's movement.

The effect of wave action on the speed of a vessel have given rise to a system of "optimum track routing" which predicts a course of maximum speed for a given vessel under predicted sea state conditions. This program is especially valuable for military operations which must be conducted at highest practical speed. It also provides a more comfortable crossing and allows lower fuel consumption.

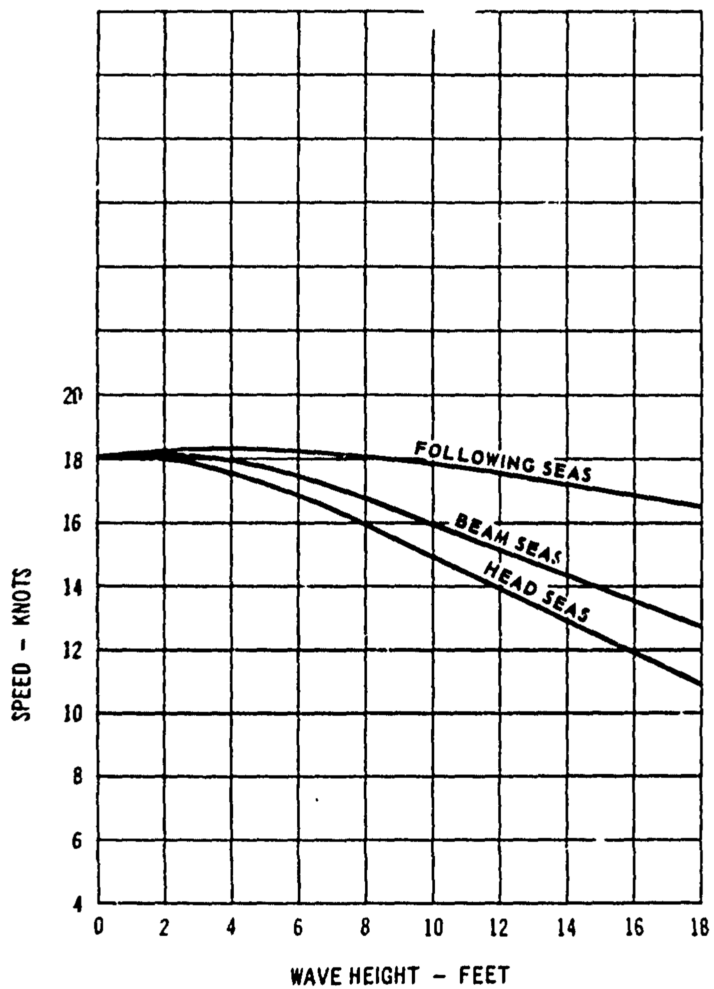


Fig. 92 VC2 - AP3 Ship Performance

Temperature may affect ship operations by the relation between air temperature and humidity and water temperature, which causes various forms of precipitation: fog, rain, sleet, snow, and hail. As impairments to visibility, these may necessitate a reduction in speed and a constant watch either visually, or on instruments. From a cargo standpoint, humidity and changes in temperature can cause damaging sweating in the holds. Ice floes and bergs are a hazard to navigation. An encrustation of ice on the hull and superstructure imposes additional weight which may impair the stability of a vessel.

Topography is important to ship operation in that it represents the configuration of the ocean floor and thereby the depth of the water. Shallows, shoals and reefs are avoided. Topography also governs the degree of protection afforded by ports and harbors.

Tides and currents play an important role in the environment of a ship by determining the depth of a harbor and speed of movement relative to the water. Currents are responsible for much of the maritime weather, since some form of adverse

condition is likely where two such currents join.

The saline content of sea water is responsible for providing ships with a very corrosive environment, both above and below the waterline. The worst corrosion problem on a ship occurs at the waterline, where a constant cycle of submergence and exposure occurs.

Marine organisms, which live in salt water, also provide an environmental problem by attaching themselves to the underwater structure. The buildup of these organisms provides additional frictional resistance to movement through the water, causing a significant decrease in speed and increase in fuel consumption. A yearly downtime is provided for hull cleaning.

Induced Environment

Induced environmental conditions are generally fewer and less severe than for aircraft. Heat from machinery and vibration from the drive train are perhaps the most significant conditions which are self-induced.

Ports and port facilities, bridges and power lines, locks and canals, navigation aids, and types of cargo are important items in establishing the induced environment. Ports and port facilities such as channels, tugs, docks, wharves, warehouses, cranes, fuel supplies, and ships stores determine, to a great extent, the degree and efficiency of transport ship operation. Man made obstacles like bridges and power lines may dictate the size of vessels which can use a given port.

The draft of a vessel, under given load and water temperature conditions, plus its size may determine whether it can operate in such man made waterways as canals and locks. Table 17 shows the ship characteristics allowed by the three most important of such facilities equipped for ocean-going traffic.

Navigation aids, on both ship and shore govern the conditions under which a vessel may operate in foul weather. The development of radio telephony, radar, shoran, loran, decca, console, direction finders, fathometers, and other devices contribute to the operating capability and safety of transport ships.

Table 17 Limiting Dimensions for Major Inland Passage Facilities

	LENGTH OF LOCKS FEET	BREADTH OF LOCKS FEET	DEPTH OF LOCKS FEET
Panama Canal	1000	110	40
St. Lawrence Seaway	768	80	27
Suez Canal (no locks)			37

4.6 DETERMINATION OF MISSION PROBLEM AND FLEET SIZES FOR COST MODEL

4.6.1 DISCUSSION

To compare the relative capabilities and costs of aircraft and ships, two missions are exercised. The first mission typifies an annual peacetime logistics mission, while the second represents an emergency military deployment. These cases permit a comparision of the transport vehicles on both a weight-limited and a space-limited basis.

4.6.2 PEACETIME LOGISTICS MISSION

A general high-density cargo lift of one million short tons between San Francisco and Singapore is chosen for this study. This is assumed to be the amount moved during a 12-month period. Of the total, 73 percent was assumed to be outbound and 27 percent inbound.

4.6.2.1 TRANSPORT AIRCRAFT

Table 18 shows the number of transport aircraft required to complete the selected mission within one year's time, based on an average utilization rate of 8 hours per day per aircraft. Aircraft were routed so as to provide the greatest weight carrying capability (shortest critical leg).

4.6.2.2 TRANSPORT SHIPS

Transport ship requirements for this mission are given in Table 19. The tonnage given in 4.6.2 was increased by 15 percent to account for extra packaging, packing,

Table 18 Transport Aircraft Requirements – General Cargo Mission

Aircraft Type	Number Required
C-54G	4742
JRM-2	1473
C-118A	1593
C-124C	1260
C-133A	489
CL-44D	462
C-130E	842
C-135B	255
707-320C	222
L-300	263
742-302	247
742-303	261
742-304	114
742-305	112
742-306	56
742-307	112
742-308	56
742-309	140
742-310	139
742-311	222
748B-15	135

and dunnage required for shipment by water. A nominal sea time of 200 days was used for general cargo vessels based on MSTS statistics for cargo operations. Special ship types which are designed specifically to reduce time in port were assigned appropriately higher sea times.

Table 19 Transport Ship Requirements – General Cargo Mission

Ship Type	Number Required
C3-S-A2	17
C1A	31
C2-S-AJ1	20
C1-M-AV1	49
VC2-S-AP3	19
C4-S-1a	13
C3-ST-14a	20
C4-S-57a	11
C4-ST-67a	17
T2-SE-A1	8*
742-320S	9
742-321S	6

* Bulk POL only, equivalent tonnage

4.6.2.3 CAPABILITY SUMMARY AND COMPARISON

Table 20 shows the capabilities of the various aircraft types. Table 21 provides this information for ships. The tables are self-explanatory.

4.6.3 THIRTY-DAY DEPLOYMENT OF AN ARMORED DIVISION

Section 4.6.2 dealt with the performance of aircraft and ships in accomplishing a weight-limited mission; this section examines these same vehicles where space is the limiting factor.

Table 20 Airlift Vehicles — General Cargo Mission

AIRCRAFT TYPE	RECIPROCATING POWERPLANT				TURBO-PROP POWERPLANT			TURBO-FAN POWERPLANT		
	C-54G	JRM-2	C-118A	C-124C	C-133A	CL-44D	C-130E	C-135B	707-320C	L-300
Critical Leg Payload (Short Tons)	5.7	22	14.3	19.6	39.75	32.1	22.25	41.50	47.75	44.65
Total Payload/Round Trip (Short Tons)	7.61	30.14	19.59	26.85	54.45	44.0	31.48	56.85	65.41	61.16
Block Speed (Knots)	175	147	208	192	245	315	254	440	440	410
Round Trip Productivity (Ton-Knots)	1,367	4,416	4,075	5,155	13,340	13,860	7,996	25,014	28,780	24,978
Round Trip Delivery (Short Tons/Aircraft/Year)	256	823	761	963	2,481	2,629	1,488	4,759	5,476	4,624
Utilization (Hours/Day)	8	8	8	8	8	8	8	8	8	8

ADVANCED TECHNOLOGY AIRCRAFT

	742-302	742-303	742-304	742-305	742-306	742-307	742-308	742-309	742-310	742-311	748B-15
Critical Leg Payload (Short Tons)	100.0	92.0	100.0	100.0	200.0	100.0	200.0	100.0	100.0	50.0	80.0
Total Payload/Round Trip (Short Tons)	136.99	126.03	136.98	136.98	273.97	136.98	273.97	136.98	136.98	68.49	109.59
Block Speed (Knots)	181	186	409	419	421	417	413	333	337	421	440
Round Trip Productivity (Ton-Knots)	24,795	23,442	56,059	57,367	115,341	57,149	113,046	45,620	46,170	28,849	48,220
Round Trip Delivery (Short Tons/Aircraft/Year)	4,926	4,658	10,636	10,893	21,918	10,869	21,457	8,665	8,772	5,482	9,00.
Utilization (Hours/Day)	8	8	8	8	8	8	8	8	8	8	8

Table 21 Sealift Vehicles – General Cargo Mission

SHIP TYPE	C3-S-A2	C1A	C2-S-AJ1	C1-M-AV1	VC2-S-AP3	C4-S-1a	C3-ST-14a
Payload (Short Tons)	11,592	7,235	10,310	6,133	10,192	12,466	9,061
Total Payload/Round Trip (Short Tons)	15,879	9,895	14,123	8,401	13,962	17,077	12,412
Block Speed (Knots)	16.55	14.04	15.46	10.54	16.55	20.34	18.01
Round Trip/Productivity (Ton-Knots)	262,797	139,150	218,342	88,547	231,071	347,346	223,540
Round Trip Delivery (Short Tons/Ship/Year)	85,905	45,418	71,321	28,899	75,534	113,391	72,983
Sea Time (Days/Year)	200	200	200	200	200	200	200

	C4-S-57a	C4-ST-67a	T2-SE-A1	742-320S	742-321S
Payload (Short Tons)	12,477	9,470	16,934(POL)	13,686	20,574
Total Payload/Round Trip (Short Tons)	17,092	12,972	23,197(POL)	18,748	28,185
Block Speed (Knots)	20.55	20.01	14.50	23.46	25.10
Round Trip/Productivity (Ton-Knots)	351,234	259,572	336,357	439,830	707,433
Round Trip Delivery (Short Tons/Ship/Year)	103,646	112,436	154,028	170,982	274,804
Sea Time (Days/Year)	238	200	280	238	238

The mission selected for this space-limited case was the transport of one ROAD Armored Division from the vicinity of San Francisco to the vicinity of Singapore within thirty days. Table 22 itemizes the particulars of the division being deployed.

4.6.3.1 TRANSPORT AIRCRAFT REQUIRED

The number of aircraft required were calculated from loading simulation studies. Aircraft with front or rear drive-on loading transported both troops and vehicles. Side loading aircraft carried only personnel and supplies. For defining the fleet size, utilization was assumed to be an average of 8 hours per day per aircraft. Aircraft were limited as to maximum payload by critical leg distance and were further restricted by loading efficiency where applicable.

Table 23 shows the number of aircraft required to carry that percentage of the ROAD Division of which they are capable,

Table 22 ROAD Armored Division

DIVISION MANEUVER BATTALIONS	6 MECHANIZED INFANTRY BATTALIONS 4 TANK BATTALIONS
Div. Major Equip. Wt, lbs	85,753,238
Major Equip. Shadow Area, ft^2 (a)	716,664
Vehicles, number	4,098
Personnel Wt, lbs, (b)	3,750,000
Personnel, Number	15,625
Accompanying Supply Wt, lbs	10,868,538
Total Division Wt, lbs	100,371,776 (50,186 Short Tons)

(a) Division closed-space shadow area with each unit treated as a rectangle (length and width)

(b) At 240 lbs per man

Table 23 Transport Airlift Requirements – Armored Division Deployment

AIRCRAFT TYPE	NUMBER REQUIRED FOR PERCENT CARRIED	APPROXIMATE WEIGHT PERCENT CARRIED (LOADING LIMITATIONS)	NUMBER REQUIRED FOR 50,186 TONS IN 30 DAYS
C-54G	445	14.6	3,055
JRM-2	146	14.6	1,003
C-118A	172	14.6	1,181
C-124C	523	58.9	888
C-133A	217	65.6	331
CL-44D	76	14.6	522
C-130E	378	56.2	672
C-135B	37	14.6	254
707-320C	31	14.6	213
L-300	147	58.7	250
742-302	154	100.0	154
742-303	163	100.0	163
742-304	81	100.0	81
742-305	76	100.0	76
742-306	37	100.0	37
742-307	76	100.0	76
742-308	38	100.0	38
742-309	93	100.0	93
742-310	92	100.0	92
742-311	156	89.0	175
748B-15	88	100.0	88

the percentage accommodated, and the number required to carry a weight equivalent to that of the Armored Division. This latter number is a device for allowing all aircraft to accomplish the same job. For example, if an aircraft type can only carry 10 percent of an Armored Division, then it is postulated that it will carry that amount for ten Armored Divisions in thirty days. This permits all aircraft to be costed on the basis of the same total weight. Different percentages carried imply different loading densities. This inconsistency is unavoidable for the Armored Division mission.

4.6.3.2 TRANSPORT SHIPS REQUIRED

Cargo ship requirements are given in Table 24. With the exception of the C1-M-AV1, all ships were capable of completing one, and only one, outbound trip. The C1-M-AV1 is too slow to complete the voyage loading and travel within 30 days. Loading efficiencies were obtained using factors for vehicles and resupply taken from Army Field Manual 101-10. Since the passenger capability of these cargo ships is very limited, it was assumed that no personnel were carried. Inasmuch as all of the POL for the Armored Division is packaged, a bulk carrier like the T2-SE-A1 was not considered part of this exercise.

Table 24 Transport Ship Requirements — Armored Division Deployment

SHIP TYPE	NUMBER REQUIRED (NO PERSONNEL CARRIED)
C3-S-A2	10
C1A	17
C2-S-AJ1	14
C1-M-AV1	*
VC2-S-AP3	17
C4-S-1a	10
C3-ST-14a	12 ***
C4-S-57a	12
C4-ST-67a	11 ***
T2-SE-A1	**
742-320S	9
742-321S	3

* Because of speed, not responsive in 30 days
** Bulk POL carrier
*** Supplies loaded aboard vehicles

4.6.3.3 CAPABILITY SUMMARY AND COMPARISON

Tables 25 and 26 summarize pertinent data on the airlift and sealift vehicles chosen for this study in accomplishing the emergency military mission.

Aircraft were compared on the basis of a productivity ratio, which is the product of the percent carried and the number of sorties flown in 30 days, divided by the total sorties required to deploy that percentage. In Table 25 the advanced technology aircraft are shown to be more efficient than the L-300 and the 707-320C.

Table 25 Capabilities of Airlift Vehicles – Armored Division Deployment

AIRCRAFT TYPE	TOTAL WEIGHT CARRIED (SHORT TONS)	SORTIES/30 DAYS	CRITICAL LEG PAYLOAD (SHORT TONS)	AVERAGE FLEET PAYLOAD (SHORT TONS)	SORTIES REQUIRED	PRODUCTIVITY RATIO
Reciprocating Powerplant						
C-54G	7,309	3.16	5.7	5.20	1406	0.033
JRM-2	7,309	2.72	22.0	18.47	396	0.100
C-118A	7,309	3.67	14.3	11.65	628	0.085
C-124C	29,549	3.42	19.6	15.52	1788	0.113
Turboprop Powerplant						
C-133A	32,900	4.22	39.75	36.00	914	0.305
CL-44D	7,309	5.40	32.10	20.08	406	0.194
C-130E	28,183	4.39	22.25	17.00	1657	0.136
Turbofan Powerplant						
C-135B	7,309	7.37	41.50	27.10	270	0.398
707-320C	7,309	7.37	47.75	32.65	224	0.480
L-300	29,400	6.69	44.65	30.00	984	0.400
Advanced Technology						
742-302	50,186	3.45	100.0	95.0	528	0.653
742-303	50,186	3.54	92.0	87.4	574	0.617
742-304	50,186	6.58	100.0	95.0	528	1.246
742-305	50,186	7.03	100.0	95.0	528	1.330
742-306	50,186	7.05	200.0	189.3	266	2.650
742-307	50,186	7.00	100.0	95.0	528	1.325
742-308	50,186	6.93	200.0	189.3	266	2.605
742-309	50,186	5.68	100.0	95.0	528	1.076
742-310	50,186	5.74	100.0	95.0	528	1.087
742-311	44,650	7.05	50.0	40.65	1099	0.571
748B-15	50,186	7.24	80.0	79.0	635	1.140

The C4-S-1a proved to be the best conventional cargo ship, with the C4-ST-67A Roll-on Roll-off being somewhat better in view of its design for this type service. The 1975 ship proved to be only slightly more productive than current models, but the 1985 ship provided about a three-fold increase in productivity.

Table 26 Capabilities of Sealift Vehicles – Armored Division Deployment

SHIP TYPE	MAXIMUM PAYLOAD (SHORT TONS)	AVERAGE FLEET PAYLOAD (SHORT TONS)	TIME/SORTIE (DAYS)	AVERAGE DELIVERY (SHORT TONS/SHIP/DAY)
C3-S-A2	11,592	4,831	23.40	206.5
C1A	7,235	2,842	24.89	114.2
C2-S-AJ1	10,310	3,451	23.44	147.2
C1-M-AV1	6,133	1,421	31.16	NA*
VC2-S-AP3	10,192	2,842	21.59	131.6
C4-S-1a	12,466	4,831	18.69	258.5
C3-ST-14a	9,061	4,026	17.83	225.8
C4-S-57a	12,477	4,076	17.58	229.0
C4-ST-67a	9,470	4,392	16.20	271.1
T2-SE-A1	16,934**	NA**	24.60	NA**
742-320S	13,686	5,368	16.09	333.6
742-321S	20,574	16,104	16.09	1000.9

* Not responsive within 30 days
** Bulk POL only

5.0 COST PARAMETER DATA

5.1 GENERAL

Ten Year Program Costs were chosen as the economic basis of comparison for the transport vehicles of this study. The Program Costs represent the total dollars required for the acquisition and operation of the several transport systems which have equal wartime transport capabilities. Cost data are presented for two payload capabilities:

(1) deployment of general cargo with weight limited payloads

(2) deployment of an Armored Division that results in space limited payloads for many but not all of the transport vehicles.

Tabulations of Program Costs versus Fleet sizes, for equal capabilities, are given in Section 8.1 for transport aircraft and in Section 8.2 for transport ships.

Program dollars per ton mile of wartime deployment capability per day is the specific parameter used to compare transport deployment cost effectiveness. 1964 dollars and short tons are used as units for both aircraft and ships.

Both MATS and MSTS operate within an Industrial Funding concept. The Industrial Fund provides that a portion of the annual Operation and Maintenance Costs are paid by the agency that uses MATS or MSTS transport services. For MATS, the O&M cost items covered by Industrial Fund are about 80 percent of the total while almost all of the Annual Operating Expense is covered for MSTS.

The level of the Industrial Fund rates are important to the various DOD agencies in that it establishes the payment rate for transport services. The Industrial Fund rates related to the various transport vehicles are plotted versus the year of introduction of the vehicle, to illustrate the cost trends.

Sensitivity comparisons are provided, to show the effects on Program Costs of variations in the major cost inputs or estimates. These effects can be related directly to the deployment capability cost comparisons. Industrial Fund rates

are relatively insensitive to variations in initial cost and wartime utilization. For this reason the sensitivity comparisons are shown for program cost but not for Industrial Fund rate.

Program costs are shown in Section 5.4.4 plotted versus three of the efficiency parameters which were defined in Section 3. The parameters chosen are V_{cru}, $P/L \times V_{cru}$ and $P/L \times R$. These plots provide a relationship between program costs and technological level.

5.2 DESCRIPTION OF COST MODEL

5.2.1 TRANSPORT AIRCRAFT

Program Costs for the 21 aircraft of this study were computed using the Military Transport System Costing Method, Section 8.1. Program Cost is defined as the total Initial Investment Cost plus ten years of Annual Operations and Maintenance. Expenditures for Design Development, Test, and Evaluation are included in the program cost for future transport aircraft. For transport aircraft, the major items of Initial Investment Cost and Annual Operations and Maintenance are:

Initial Cost	Annual Operations and Maintenance
Basic Fleet Aircraft	Maintenance Material
Command Support Aircraft	Personnel Pay and Allowances
Advanced Attrition Buy Aircraft	Replacement Training & Personnel Transportation
Maintenance Spares	
Personnel Training	Base Maintenance
Transportation	Aircraft POL
Aerospace Ground Equipment	Miscellaneous Costs
Stocks POL	
Non-aircraft Supply	

5.2.2 TRANSPORT SHIPS

Program Costs for the 12 ships were computed using the costing method for the Military Sea Transport System, Section 8.2. As with the aircraft, Program Cost includes Initial Cost plus 10 years Annual Operating Expense. Since MSTS ships have a 25 year life, by Public Law 86-518 (1960), the ship initial cost is prorated for a ten year period so that the ship time period will be consistent with the time period

assumed for MATS aircraft. Major items of Initial Cost and Annual Operating Expense for ships are:

Initial Cost	Annual Operating Expense
Complete Delivery Price	Maintenance and Repair
	Crew Pay and Subsistence
	Fuel Costs
	Port Charges
	Supplies, Equipage and Other Costs
	Overhead Cost
	Cargo Handling Cost

5.3 DESCRIPTION OF INPUT ASSUMPTIONS

The assumptions used in the cost analysis are given in Tables 27 and 28. It is assumed that all aircraft are operated by MATS and all ships are operated by MSTS. Unit flyaway costs for existing aircraft, except for the JRM-2, were estimated using an 85 percent learning curve for airframe production, considering the latest available purchase price and number of aircraft produced. Flyaway costs for the JRM-2 and all future aircraft were estimated, in 1964 dollars, by the same type of detailed cost estimates that are used to cost aircraft proposals. The DDT&E costs include all basic engineering and development, tooling, five test aircraft (including one static test article and one fatigue test article), structural testing and engine development costs. The production costs include sustaining engineering and tooling, production labor and materials, purchased equipment and direct charges. Costs for engines and electronics for all aircraft are assumed to be independent of fleet size. All costs of existing aircraft have been adjusted to 1964 levels by using an escalation factor of 7 percent per year for airframes and 3 percent per year for engines and equipment. This is an estimate based on review of past costing data. Purchase prices and operational costs of ships were estimated using the method given in Section 8.2.

The required number of production aircraft is obtained by adding command support and advanced attrition buy aircraft to the number of Unit Equipment aircraft determined in Section 4.6. The number of ships required is obtained directly from Section 4.6.

Table 27 Assumptions For Aircraft

AIRCRAFT	JRM-2	C-54G	C-124C	C-118A	C-133A	C-130E	CL-44D4	C-135B	707-320C	L-300	742-302 (LOBOY)
Unit Flyaway Cost (1)	2.138	.993	3.047	1.546	5.085	2.805	3.029	4.339	6.800	6.160	11.739
A/C Production Qty.	1822	5866	1559	1971	605	1042	571	315	275	323	306
Total Cost DDT&E (1)	0	0	0	0	0	0	0	0	0	200	725
Cost of One Engine (1)	.124	.023	.124	.057	.183	.093	.116	.220	.220	.270	.400(2) .300
No. Engines per A/C	4	4	4	4	4	4	4	4	4	4	4/3
Cost of Electronics	.053	.011	.053	.057	.068	.120	.120	.132	.132	.160	.200
Weight Empty, lbs	80,700	38,700	102,200	53,000	113,800	71,200	88,600	104,900	132,000	127,300	244,000
Wt Electronics, lbs	1,800	600	1,800	1,800	1,800	2,100	2,100	2,100	2,100	2,600	3,250
Max Payload, tons	23.3	9.6	2[illegible].5	14.25	48.5	22.5	32	43.25	47.5	48	100
Fuel Cost, $/Gal.	.171	.171	.171	.171	.10	.10	.10	.10	.10	.10	.10
Fuel Used, Gal./Hr	356	200	480	310	1240	650	690	1690	1840	1750	460
Mission Time (2200 N. Mi.), Hrs	15	12.9	12.5	10.7	8.75	8	7.15	5.1	5.15	5.4	13.3
Crew Composition											
Pilots	3	3	3	3	3	3	3	3	3	3	3
Navigators	2	2	2	2	2	2	2	2	2	2	2
Airmen	3	2	3	3	3	3	3	3	3	3	3
	742-303 (LOBOY)	742-304 (LFC)	742-305	742-306	742-307	742-308	742-309	742-310	742-311	748B-15	
Unit Flyaway Cost (1)	11.114	23.336	12.563	25.935	11.908	23.655	11.957	11.610	6.484	12.201	
A/C Production Qty.	323	141	139	69	139	71	173	172	275	167	
Total Cost DDT&E (1)	685	1618	580	1420	535	1220	560	540	305	578	
Cost of One Engine (1)	.400(2) .500	.750(3) .100	.300	.750	.300	.750	.250	.250	.250	.300	
No. Engines per A/C	4/2	4/4	6	6	6	6	6	6	4	6	
Cost of Electronics	.200	.200	.160	.200	.160	.200	.160	.160	.132	.160	
Weight Empty, lbs	220,800	377,400	260,500	527,200	242,500	488,200	268,300	256,300	127,900	267,300	
Wt Electronics, lbs	3,250	3,250	2,600	3,250	2,600	3,250	2,600	2,600	2,100	2,600	
Max Payload, tons	100	100	100	200	100	200	100	100	50	80	
Fuel Cost, $/Gal.	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	
Fuel Used, Gal./Hr	475	2090	3282	5922	3077	5702	2370	1516	1794	3390	
Mission Time (2200 N. Mi.), Hrs	12.3	5.6	5.25	5.3	5.3	5.45	6.3	6.55	5.23	5.4	
Crew Composition											
Pilots	3	3	3	3	3	3	3	3	3	3	
Navigators	2	2	2	2	2	2	2	2	2	2	
Airmen	3	3	3	3	3	3	3	3	3	3	

The following assumptions are common to all aircraft:

Utilization	Attrition Rate	Crews/Unit Equipment Aircraft	Unit Equipment Aircraft/Wing	Base of Operation
1825 Hr/Yr	1 Aircraft per 100,000 Hours	2.33	48	Non-Tenant Assume Base Exists

(1) All costs are in millions of dollars unless otherwise noted.
(2) LOBOY aircraft have 4 regenerative turboprop cruise powerplants, plus auxiliary turbofans used for takeoff only.
(3) Laminar Flow Control (LFC) aircraft has 4 cruise turbofans plus 4 bleed-burn LFC units.

Table 28 Assumptions For Ships

Ship	Prod. Qty.	Outfit Complexity	Machinery	Machinery Location	SHP_N	Sea Speed Knots	Length Bet. Perp. Feet	Beam Feet	Depth to Uppermost Cont. Deck Feet	Cubic No.	Days at Sea Per Yr.	Bale Capacity Cu. Ft.
C4-S-1a	13	Typical (Reefer)	Steam Turbine	Amidships	17,500	20	528	76	44.5	17,857	200	737,000
C4-S-57a(1)	11	Typical (No Reefer)	Steam Turbine	Amidships	16,500	20.5	529	75	42.5	16,862	238	642,897
C3-S-A2	17	Typical (No Reefer)	Steam Turbine	Amidships	8,500	16.5	465	69.5	42.5	13,735	200	736,000
C2-S-AJ1	20	Typical (No Reefer)	Steam Turbine	Amidships	6,000	15.5	435	63	40	10,962	200	543,000
VC2-S-AP3	19	Typical (No Reefer)	Steam Turbine	Amidships	8,500	16.5	436.5	62	38	10,784	200	453,000
C1A	31	Typical (No Reefer)	Steam Turbine	Amidships	4,000	14	390	60	37.5	8,775	200	446,000
742-320S(2)	9	Typical (No Reefer)	Steam Turbine	Amidships	24,000	23.5	598	76	46.5	21,133	238	830,000
742-321S(3)	6	Typical (No Reefer)	Steam Turbine	Amidships	66,000	25	750	106	72	57,240	238	2,770,000
C1-M-AV1	49	Typical (No Reefer)	Diesel	Aft	1,700	10.5	320	50	29	4,640	200	219,754
C4-ST-67a(4)	17	Typical (RO/RO)	Steam Turbine		17,500	20	499.5	83	53	21,973	200	946,800
C3-ST-14a(4)	20	Typical (RO/RO)	Steam Turbine		11,220	18	465	78	48.8	17,682	200	813,116
T2-SE-A1	8	Typical (Tanker)	Turbo Electric	Aft	6,000	14.5	503	68	39.3	13,425	280	---

(1) Cargo Ship with Advanced Cargo Handling Gear
(2) 1975 Cargo Ship with Advanced Cargo Handling Gear
(3) 1985 Cargo Ship
(4) Roll on/Roll off Design

Attrition for ships is assumed to be negligible

Number of crews per ship = 1

5.4 PLOTTED DATA

This section presents the cost comparisons developed for the 21 aircraft transports and the 12 ships considered in the cost section of this study.

5.4.1 PROGRAM COST - DOLLARS/TON MILE OF DEPLOYMENT CAPABILITY PER DAY

Shown, in Fig. 93, is the peacetime cost per ton mile of daily wartime deployment capability for a selected group of aircraft and ships. The selection was made to cover the range of costs for both types of transport vehicles. Considering presently operating and future vehicles, the aircraft costs are 30 to 60 times as high as ship costs depending on range.

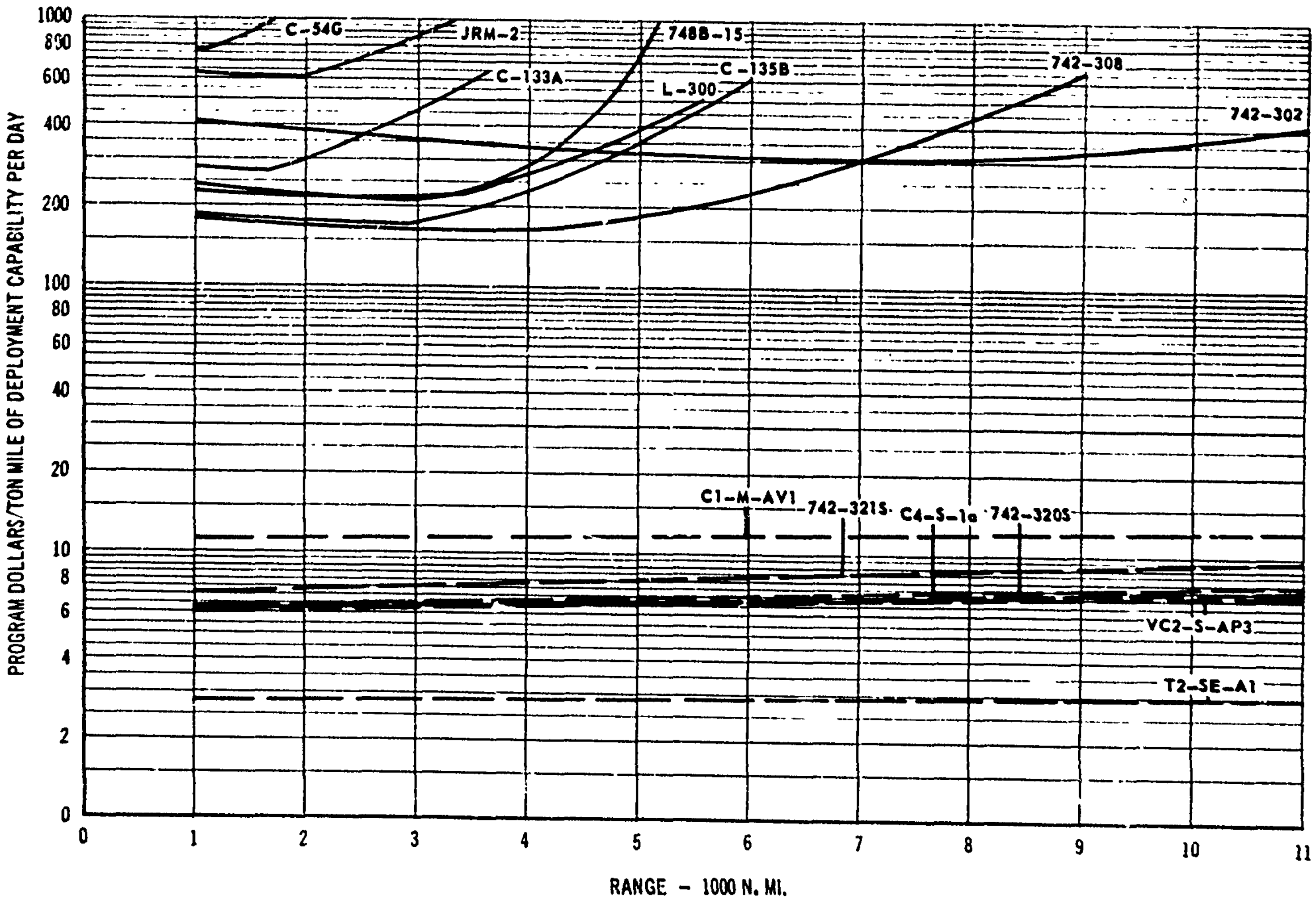


Fig. 93 Deployment Capability Cost for General Cargo and Weight–Limited Payloads

Fig. 94 presents the relative costs of 21 aircraft versus range. The suporiority of the two LOBOYS (742-302, - 303) and the LFC aircraft (742-304) at ranges greater than 7500 nautical miles should not necesrarily be taken as a general conclusion. Refer to Section 3.2.6 for a discussion of the P/L - Range characteristics of each vehicle.

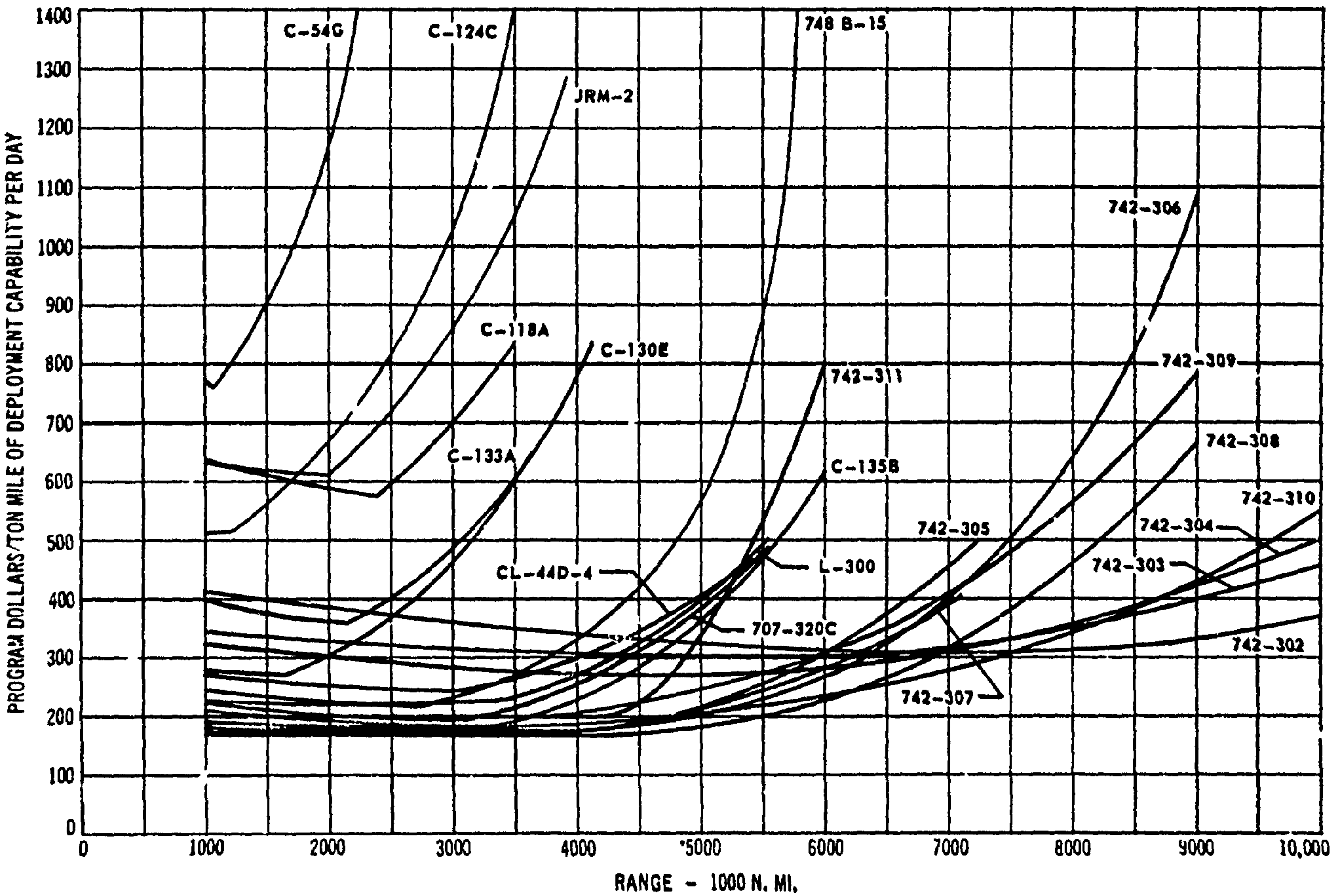


Fig. 94 Aircraft Deployment Capability Cost General Cargo - Weight Limited Payload

In Fig. 95 the relative costs of 12 ships versus range are presented. In this plot, the program cost of the tanker is much lower than the costs for cargo ships because the tanker has no appreciable cargo handling costs associated with its payload.

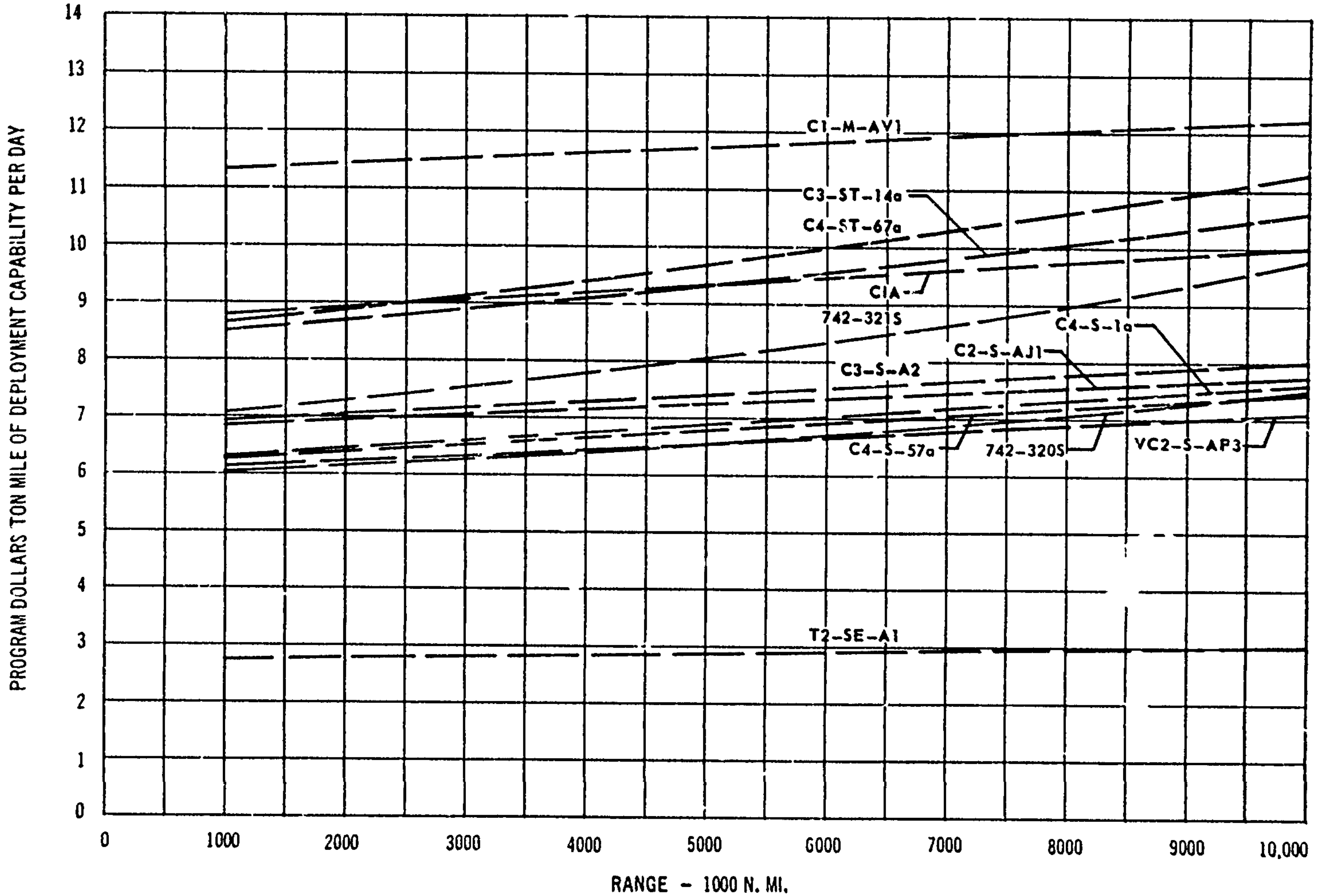


Fig. 95 Ship Deployment Capability Cost – General Cargo – Weight Limited Payload

The peacetime program cost per ton mile of daily wartime deployment capability for selected aircraft and ships when transporting Armored Divisions is plotted in Fig. 96. It is assumed that an Armored Division is deployed from the West Coast to Singapore within 30 days. Cargo ships and all future aircraft except for the 742-311 have the capability of transporting all equipment associated with Armored Divisions. The C1-M-AV1 cannot load and deliver its cargo within 30 days and the T2-SE-A1 tanker cannot carry Armored Division equipment. Much of the equipment is outsized for existing aircraft and they are not capable of deploying a complete Armored Division. The percentage of total Armored Division weight which can be carried is noted in parentheses after each aircraft designation. For comparison, the fleet sizes of all aircraft are based on deploying a total weight equal to the weight of an Armored Division. Those aircraft which are space limited to carry less than 100 percent of the Armored Division are, in effect, carrying weight limited payloads, each of different loading density. This tends to color the result and the relatively better position of the space limited aircraft curves should be understood as of interest for their qualitative value and should be interpreted with a careful understanding of the mission problem.

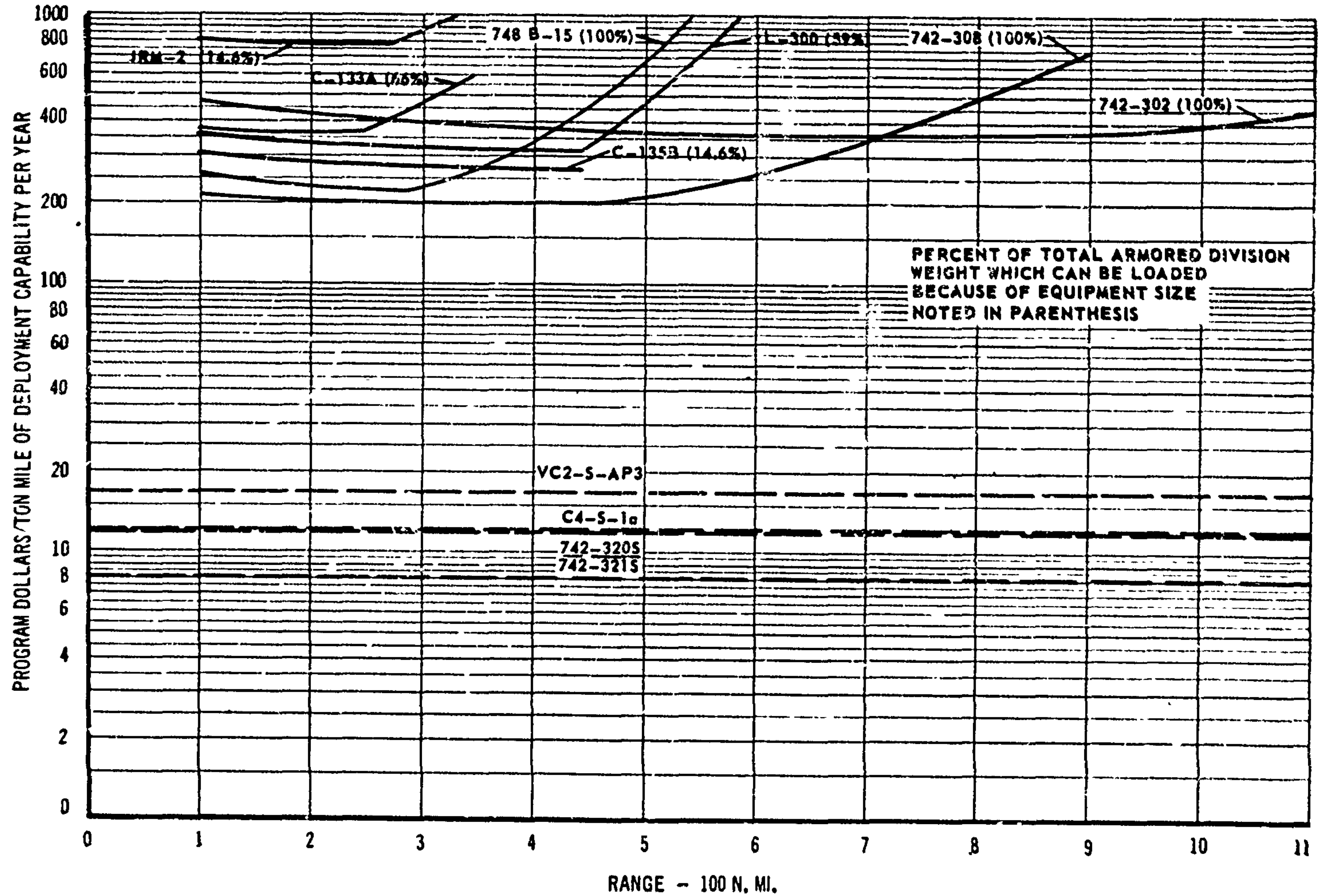


Fig. 96. Deployment Capability Cost Armored Divisions

Fig. 97 shows the distribution of capability costs for the 21 aircraft of the study when deploying Armored Divisions. See the discussion on page 166 for interpretation of the costs for aircraft which are load limited because of size.

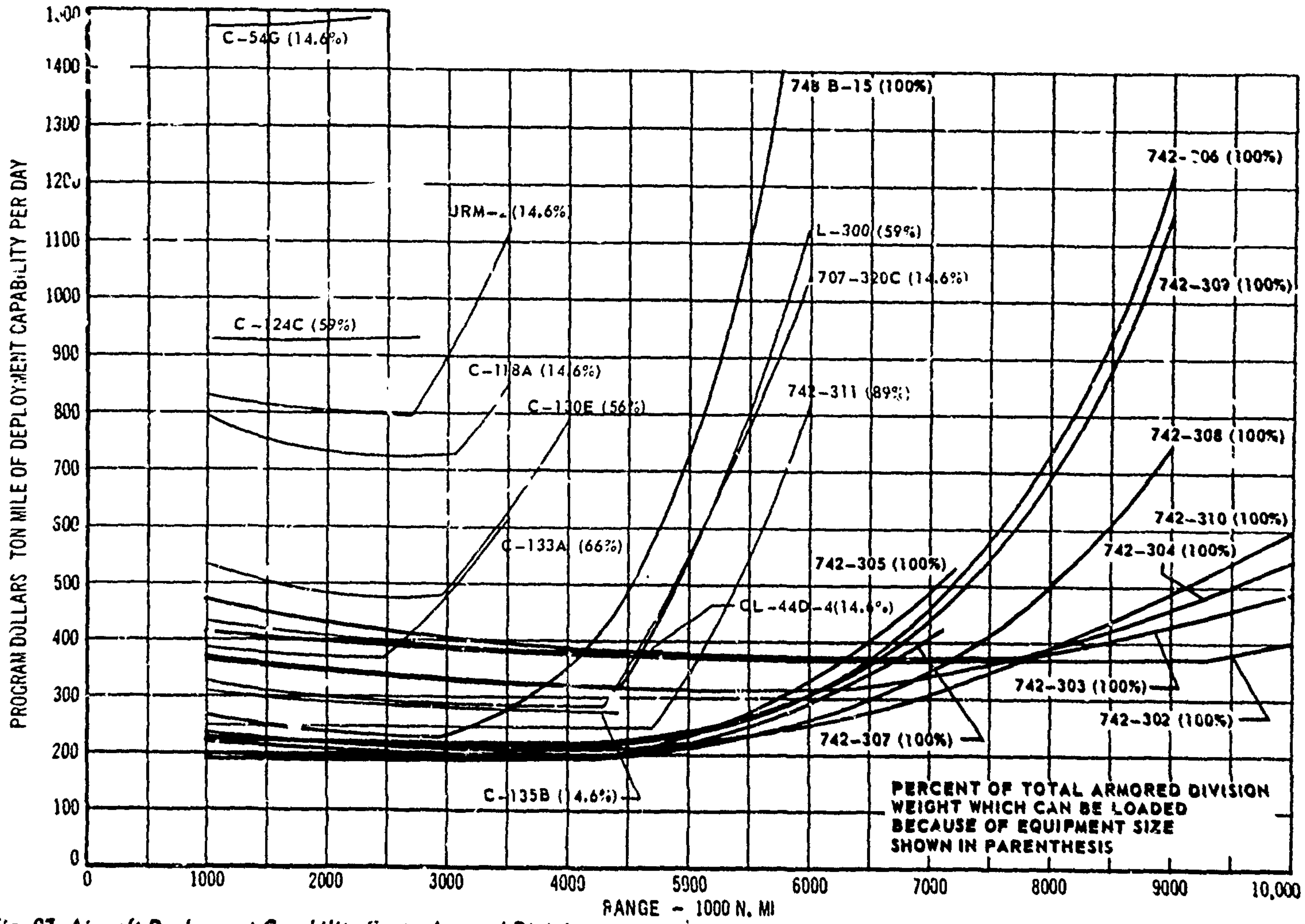


Fig. 97 Aircraft Deployment Capability Cost Armored Divisions

The capability costs of 10 ships to deploy an Armored Division are presented in Fig. 98. Two of the 12 ships of Fig. 95 are not included here. They are the C1-M-AV1 and the T2-SE-A1. The C1-M-AV1 cannot meet the requirements for a 30 day mission because of its slow speed. The T2-SE-A1 is not required because it is assumed that the POL required for an Armored Division would be shipped in barrels.

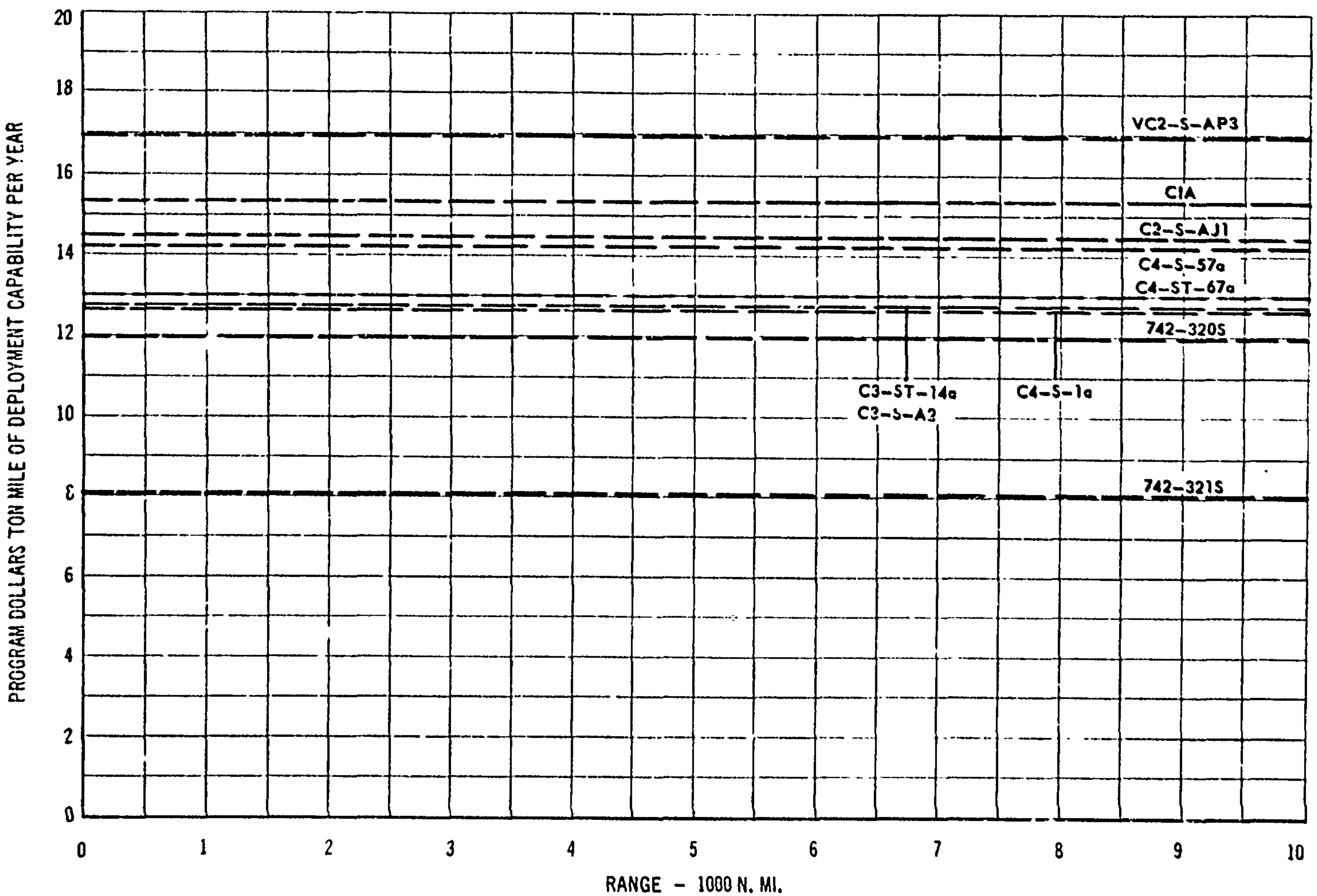


Fig. 98 Ship Deployment Capability Cost Armored Divisions

5.4.2 INDUSTRIAL FUND RATE -- CENTS/TON NAUTICAL MILE

Industrial Fund rates are established so that certain peacetime operation and maintenance costs are paid by the using agency. For MATS transports, the portion of each O&M cash item charged to the Industrial Fund is given in Section 8.1. Since one Industrial Fund rate for channel traffic is used for the entire MATS fleet, the average operation and maintenance cost per ton mile for the fleet mix is used to determine this rate. In 1962 the MATS load factor on channel traffic was less than 70 percent. For MSTS cargo transports, it is assumed that all Annual Operating Expense is charged to the Industrial Fund.

Plotted, in Fig. 99, is the revenue rate possible for each transport vehicle if it carried a full weight limited cargo and was the only transport operated by MATS or MSTS. Since neither of these conditions existed in 1962, the actual published Industrial Fund Rates were much higher than those shown here. The MATS Special Assignment Airlift rate was 15 cents/ton mile and the equivalent MSTS rate, including terminal costs, was about 2 cents/ton mile if the cargo density was 25 lbs/cu ft.

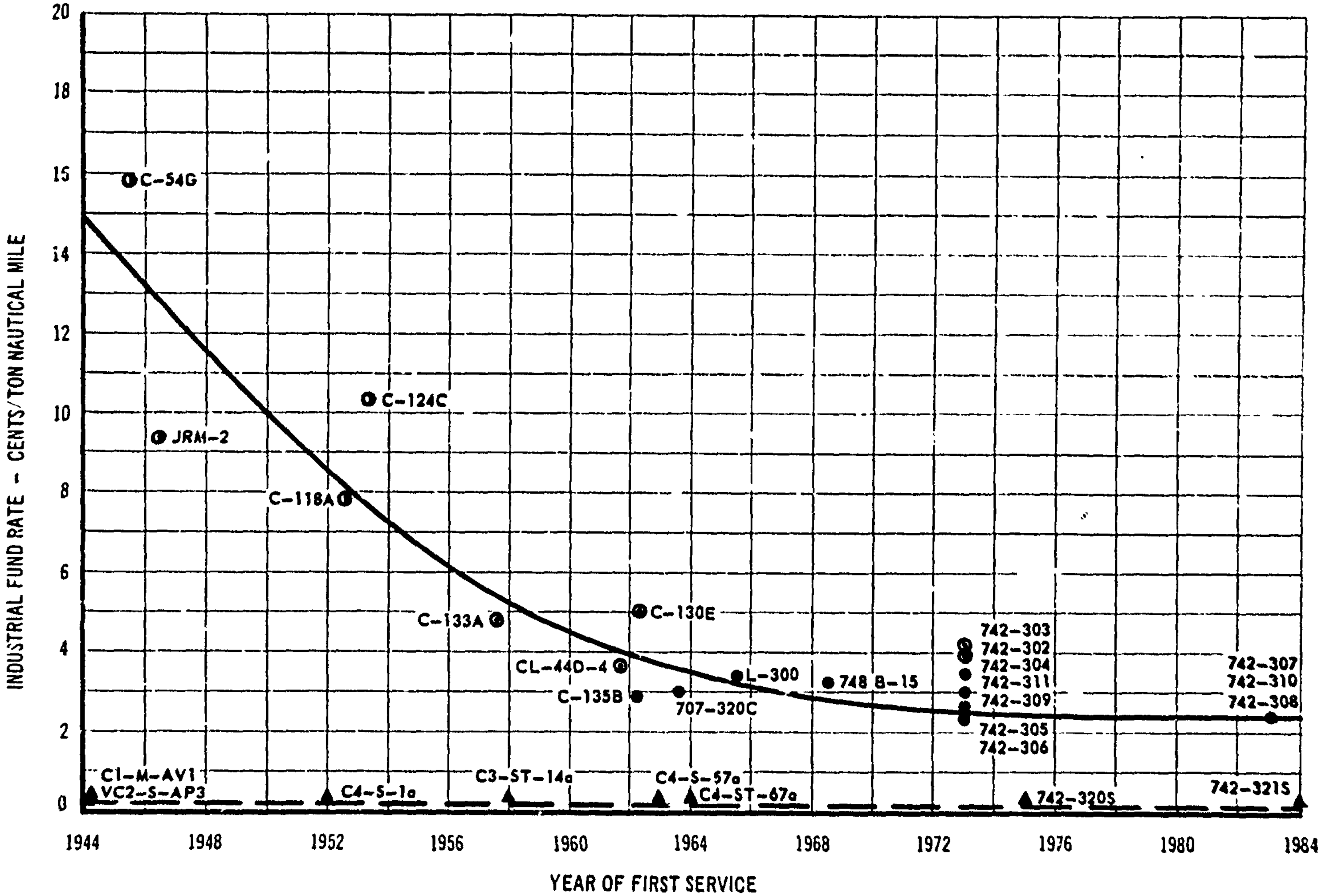


Fig. 99 Industrial Fund Rates General Cargo – Weight Limited Payload

Fig. 100 shows a plot of the revenue rates of transport vehicles for the peacetime deployment of Armored Divisions. As in Fig. 96 the percentage of total Armored Division weight which can be carried is noted in parentheses after the aircraft designation. The C1-M-AV1 and the T2-SE-A1 are not included in this plot because the C1-M-AV1 cannot meet the 30 day mission requirement and there is no suitable cargo (bulk POL) for the T2-SE-A1.

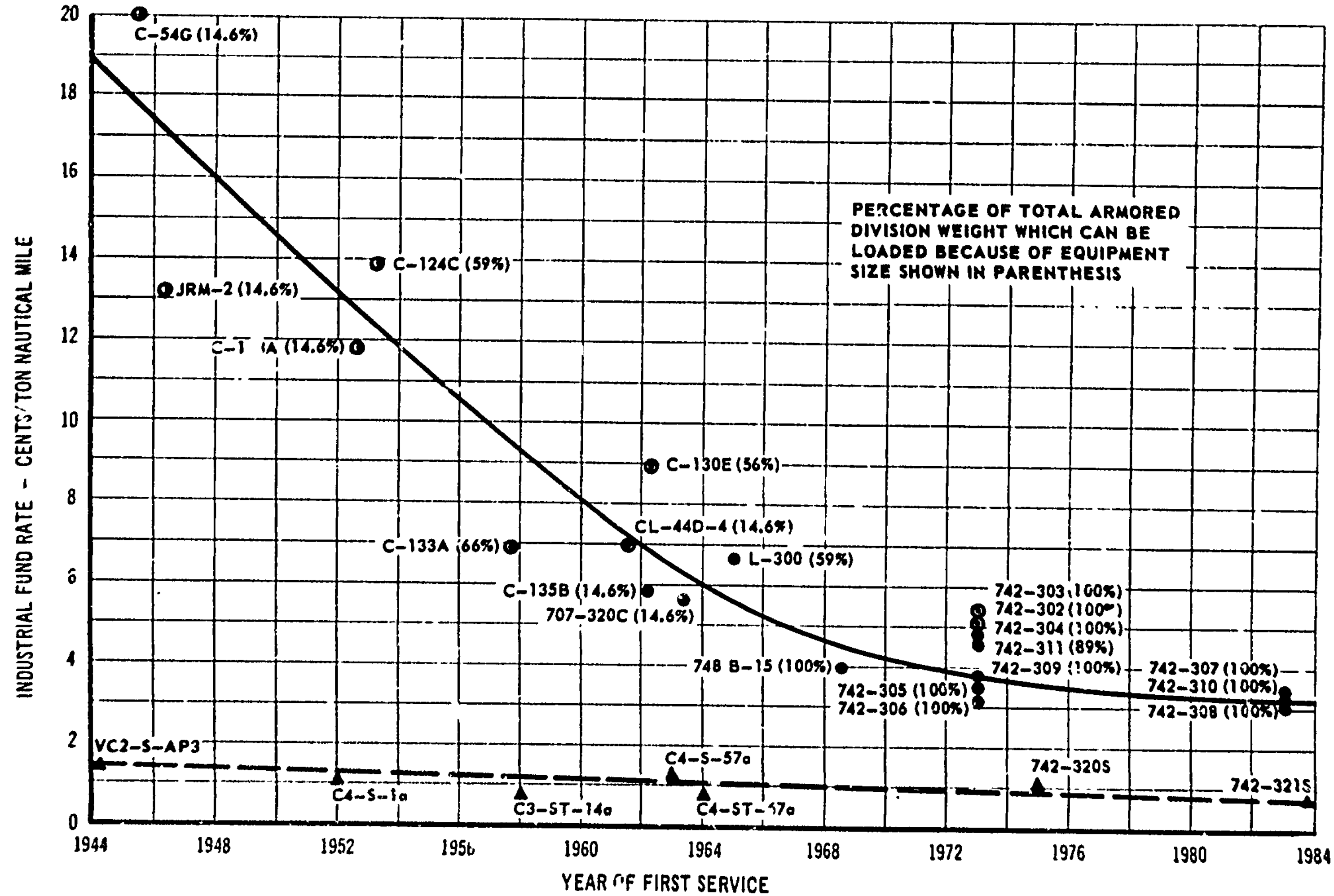


Fig. 100 Industrial Fund Rates Peacetime Deployment Exercise - Armored Division

5.4.3 SENSITIVITY COMPARISONS

Fig. 101 shows the percent change in aircraft program costs for variations in the airframe costs as estimated for the production quantities shown in Table 27 for each aircraft. Airframe cost is the major parameter affecting transport aircraft program cost, especially for production quantities of 200 or less.

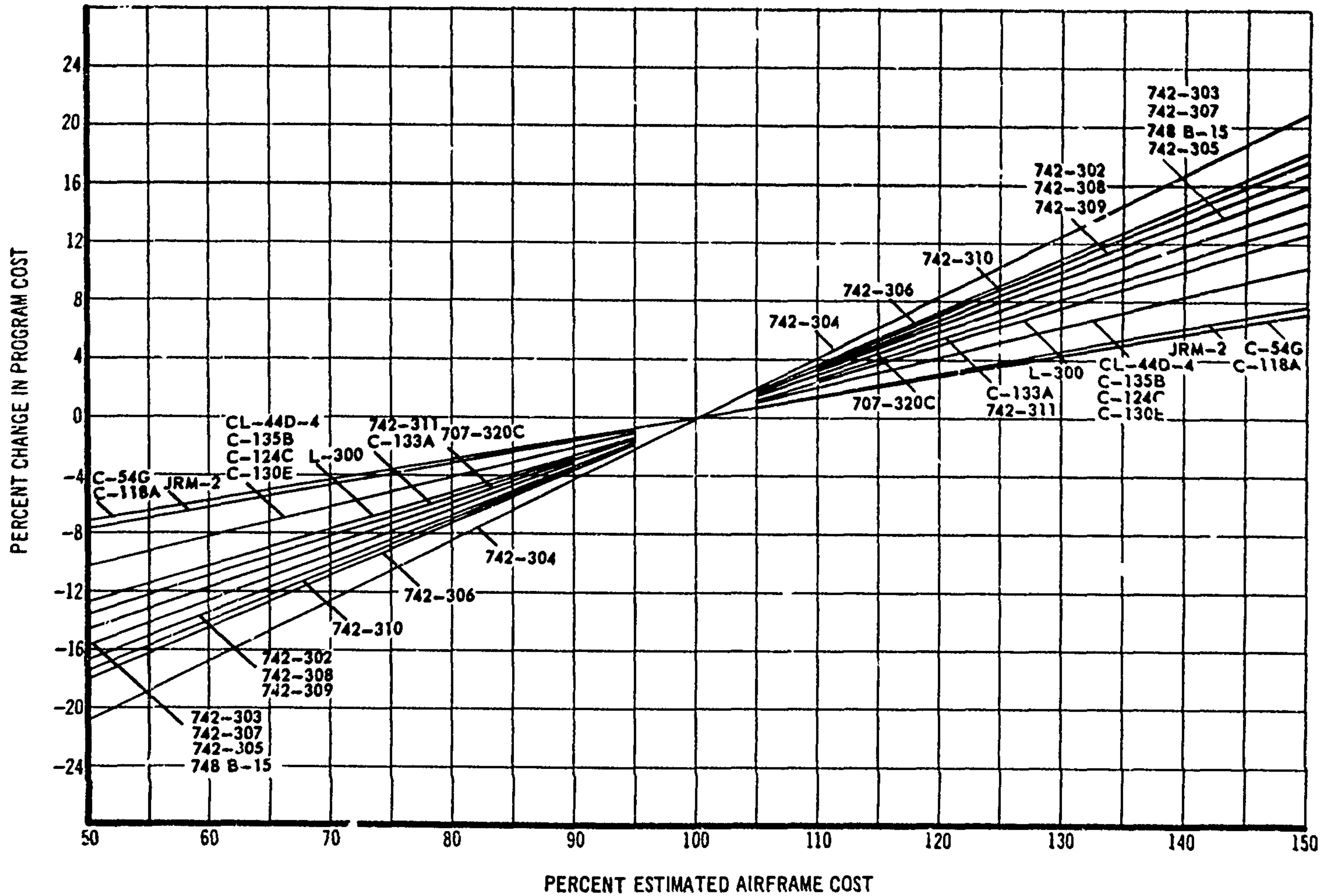


Fig. 101 Sensitivity Comparison Airframe Cost versus Program Cost

The percent change in ship program cost for variation in estimated ship delivery price is plotted in Fig. 102. No learning curve has been assumed for ship production quantities and the effect of ship cost is generally much less than the effect of airframe cost.

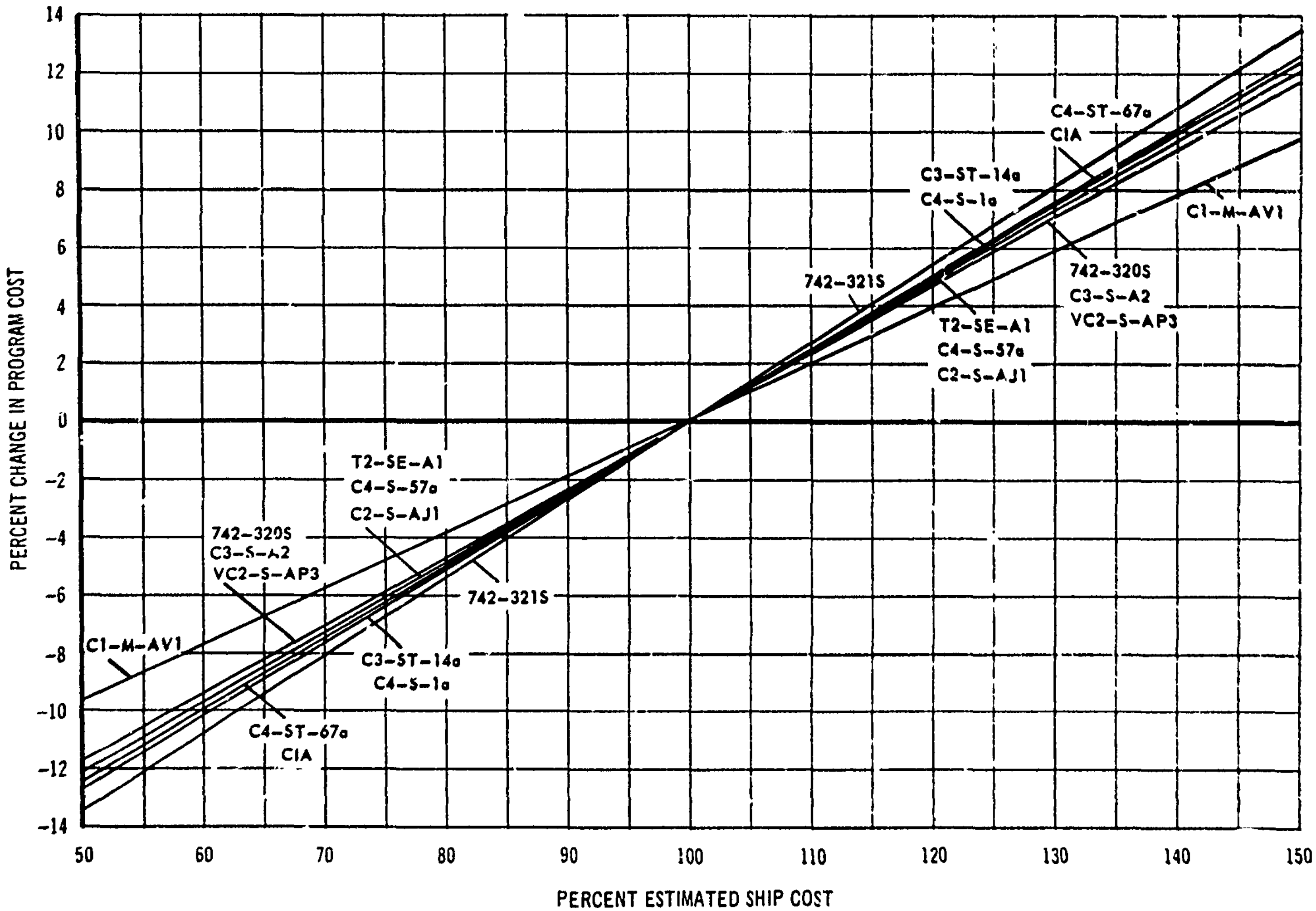


Fig. 102 Sensitivity Comparison   Ship Cost versus Program Cost

Shown, in Fig. 103, is a plot of the percent change in aircraft program costs for variations in wartime utilization As the wartime utilization decreases from 8 hours/day, the fleet size required to perform the mission increases and unit airframe cost decreases. An increase in daily utilization results in opposite changes. The effect of the change in unit airframe cost is insignificant compared to the major impact on program cost resulting from the change in fleet size.

The cost comparison, shown in Fig. 103, is based on a constant peacetime utilization of 5 hours per day. It is probable that increases in wartime utilization would require increases in crew and maintenance manning above the level required by the 5 hour peacetime utilization. The resulting increase in program cost per wing would somewhat reduce the savings realized by increased wartime utilization and the consequent reductions in fleet size required. This however is a secondary correction and is not included in Fig. 103.

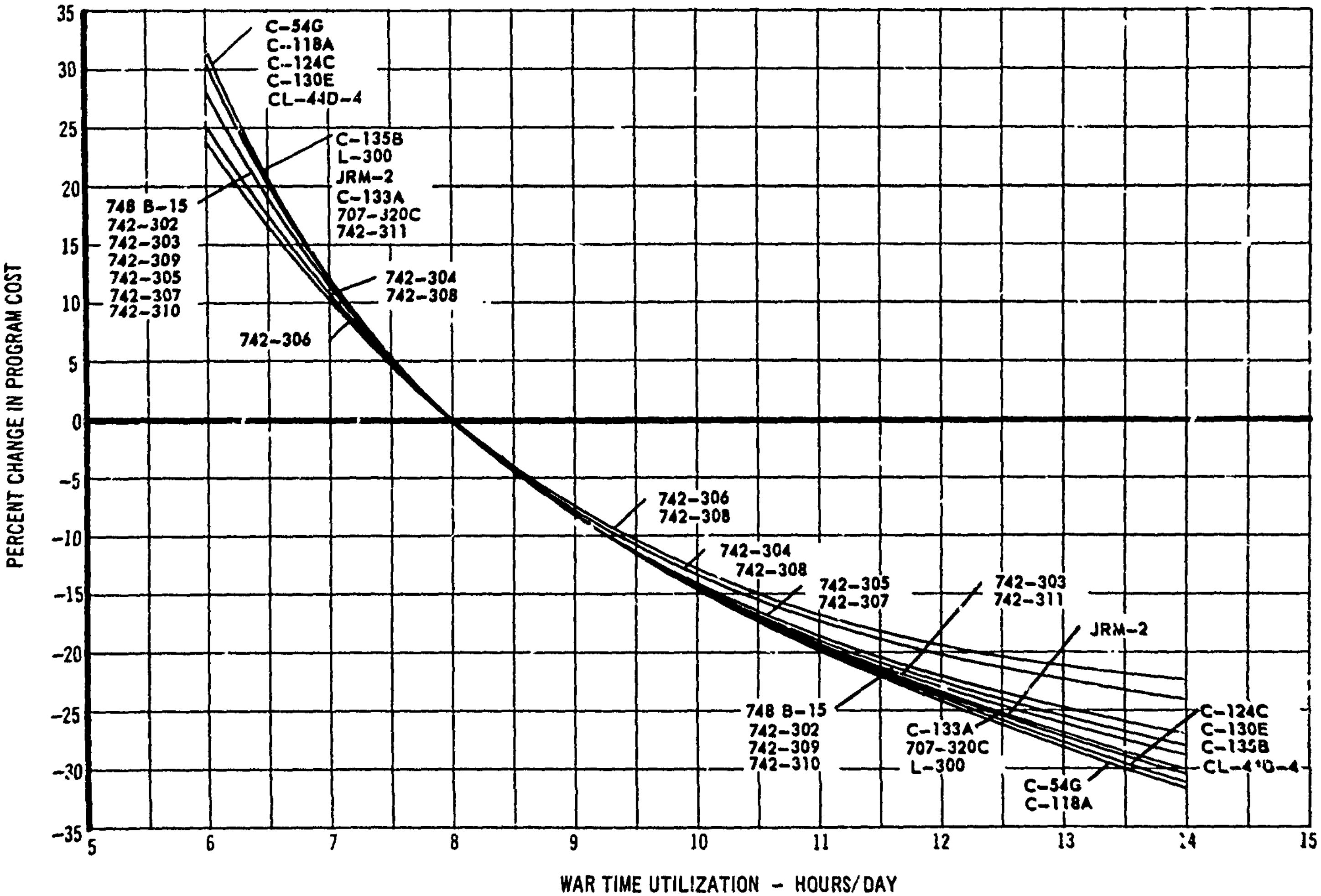


Fig. 103 Sensitivity Comparison Aircraft Wartime Utilization versus Program Cost

Fig. 104 shows the percent change in ship Program Cost for changes in assumptions on percent of bale capacity (space load factor) used for cargo handling cost. Analysis of MSTS data shows that the ratio of actual measurement ton nautical miles to the total measurement ton nautical mile capability is approximately 1 to 3.3. Therefore, a load factor of 0.3 is used in this study for determining the amount of cargo loaded per year. Since the magnitude of cargo handling costs is large, variations in percent bale capacity can have a significant effect on ship program cost.

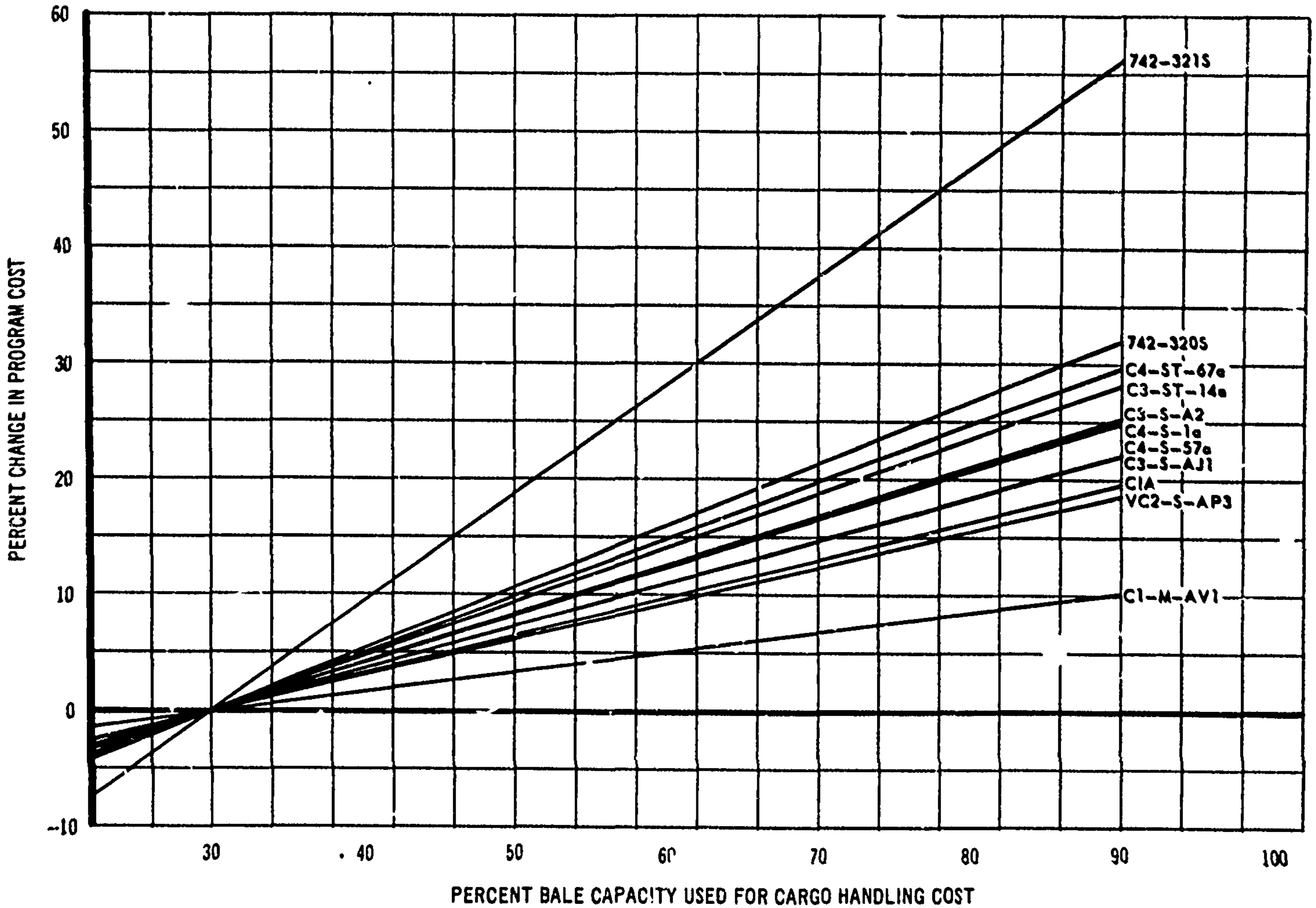


Fig. 104 Sensitivity Comparison Ship Cargo Handling Cost Factor versus Program Cost

5.4.4 PROGRAM COST VERSUS PERFORMANCE PARAMETERS

Ten Year Program Costs for the various aircraft transports are plotted versus the performance parameters defined in Section 3. Similar plots for ship transports do not show well defined trends and these comparisons are not plotted. However, a tabulation of Program Costs for the various ships, with fleet size determined by two levels of wartime capability, is given in Section 8.2.

In Fig. 105, Ten Year Program Costs for the 21 aircraft fleets are presented versus design cruise speed in knots. Since the program costs are based on fleet sizes for deployment of Armored Divisions (space limited payloads), aircraft with severe space limitations are shown as being less effective, on an economic basis.

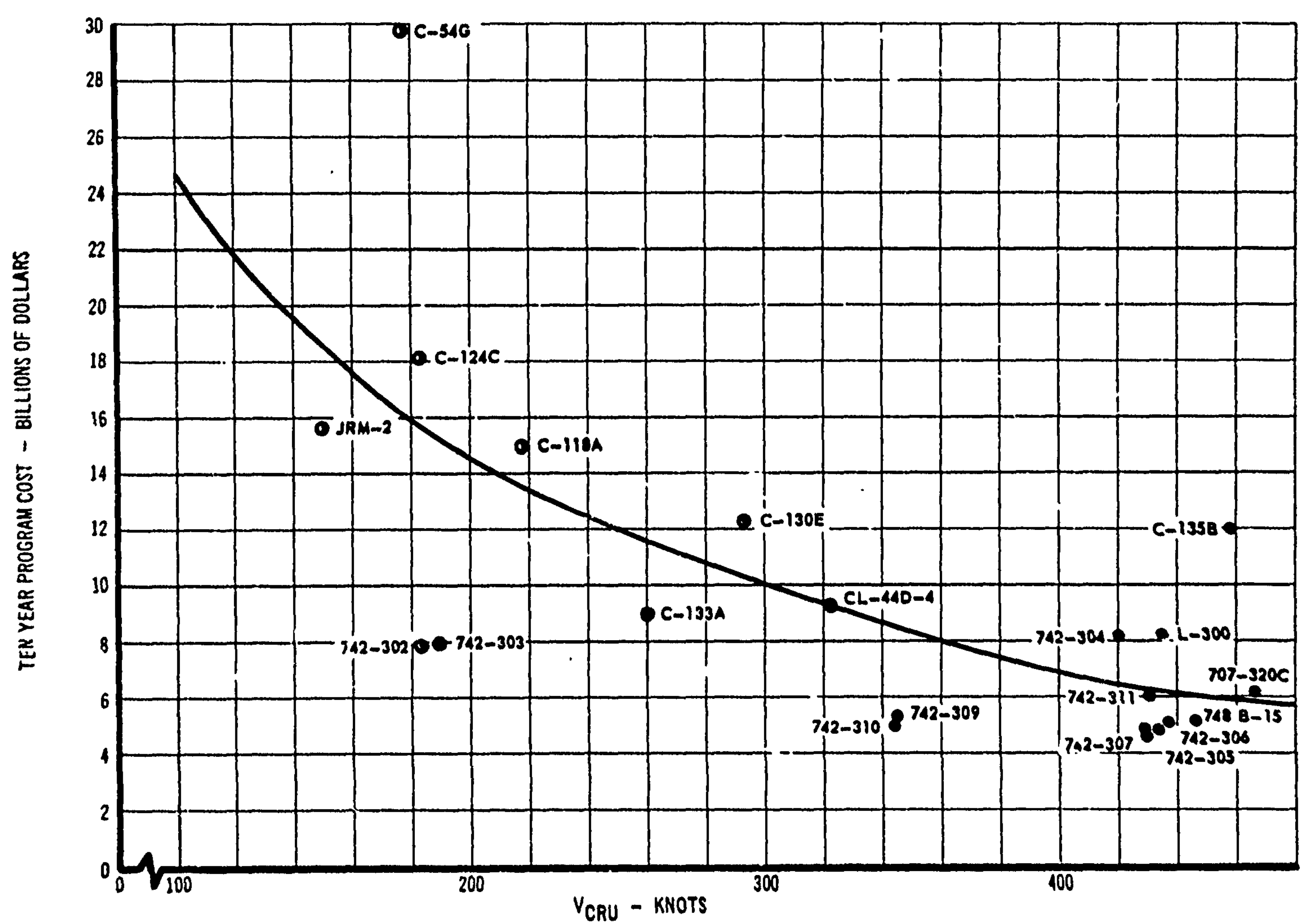


Fig. 105 Ten Year Program Cost versus V_{CRU} For Aircraft

In Fig. 106, Ten Year Program Costs, for the aircraft fleets, are presented versus the performance parameter payload (P/L) in short tons multiplied by cruise speed (V_{cru}) in knots. Although fleet sizes are based on the space limited payloads for deployment of Armored Divisions, the payloads used to determine the performance parameters are the maximum weight limited payloads. It is significant that program costs for the Models 742-306 and -308 are higher than might be expected. Since these aircraft have ton-knot capabilities which are double that of the next largest of the remaining aircraft, the required fleet sizes are only about one-half as large. Furthermore, the DDT&E expenditures, which are independent of fleet size, are very large. The small fleet sizes result in high production and DDT&E costs per aircraft. Therefore, for the chosen mission, the Models 742-306 and -308 are more expensive than aircraft of lower productivity. This effect is directly dependent on the choice of the cost problem. A larger transport requirement would reduce, relatively, these large aircraft unit costs and tend to flatten the right hand side of the curve.

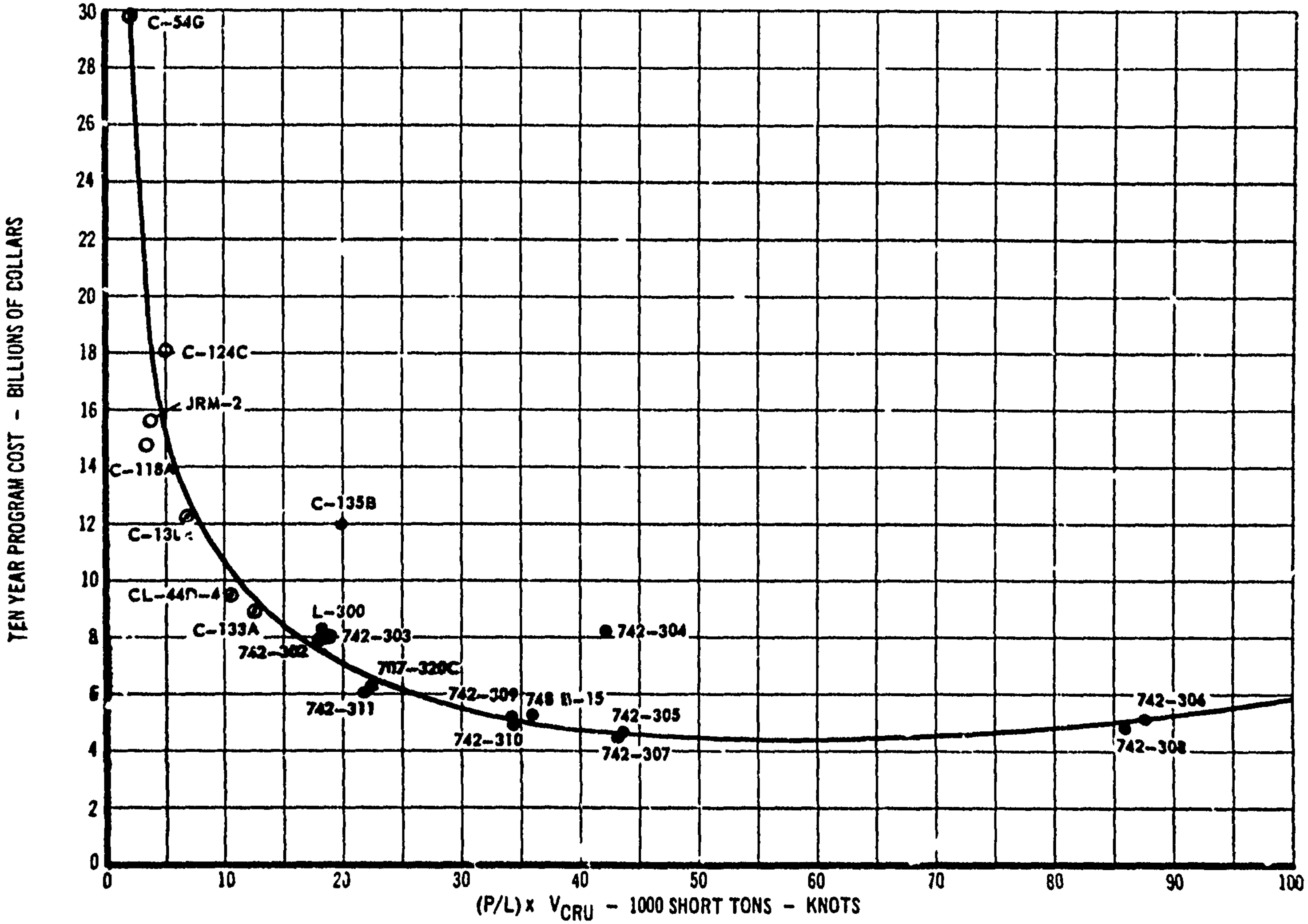


Fig. 106 Ten Year Program Cost versus (P/L) x V_{CRU} For Aircraft

The relative Ten Year Program Costs for the aircraft fleets plotted versus the performance parameter payload (P/L) in short tons multiplied by range (R) in nautical miles are presented in Fig. 107. The payload and range used in the performance parameter are the maximum weight limited payload and the maximum range over which that payload can be carried. The Program Costs, however, are based on space limited payloads for the particular range which results in maximum fleet size for the deployment capability required.

The curves of this section (particularly Figs. 93 and 96) compare program costs for several ships and aircraft, present and future. For these cost values it is shown that a factor of 15 to 60 exists between shipping by sea and shipping by air. Readers with experience in interpreting cost data will recognize that a considerable change in results and conclusions may be had by changing the cost model. This point is mentioned to caution the reader to avoid a too hasty conclusion from a brief scanning of these foregoing curves.

An example of the change to the relative costs and effectiveness of sea and air transport which can be obtained by changing the problem is shown

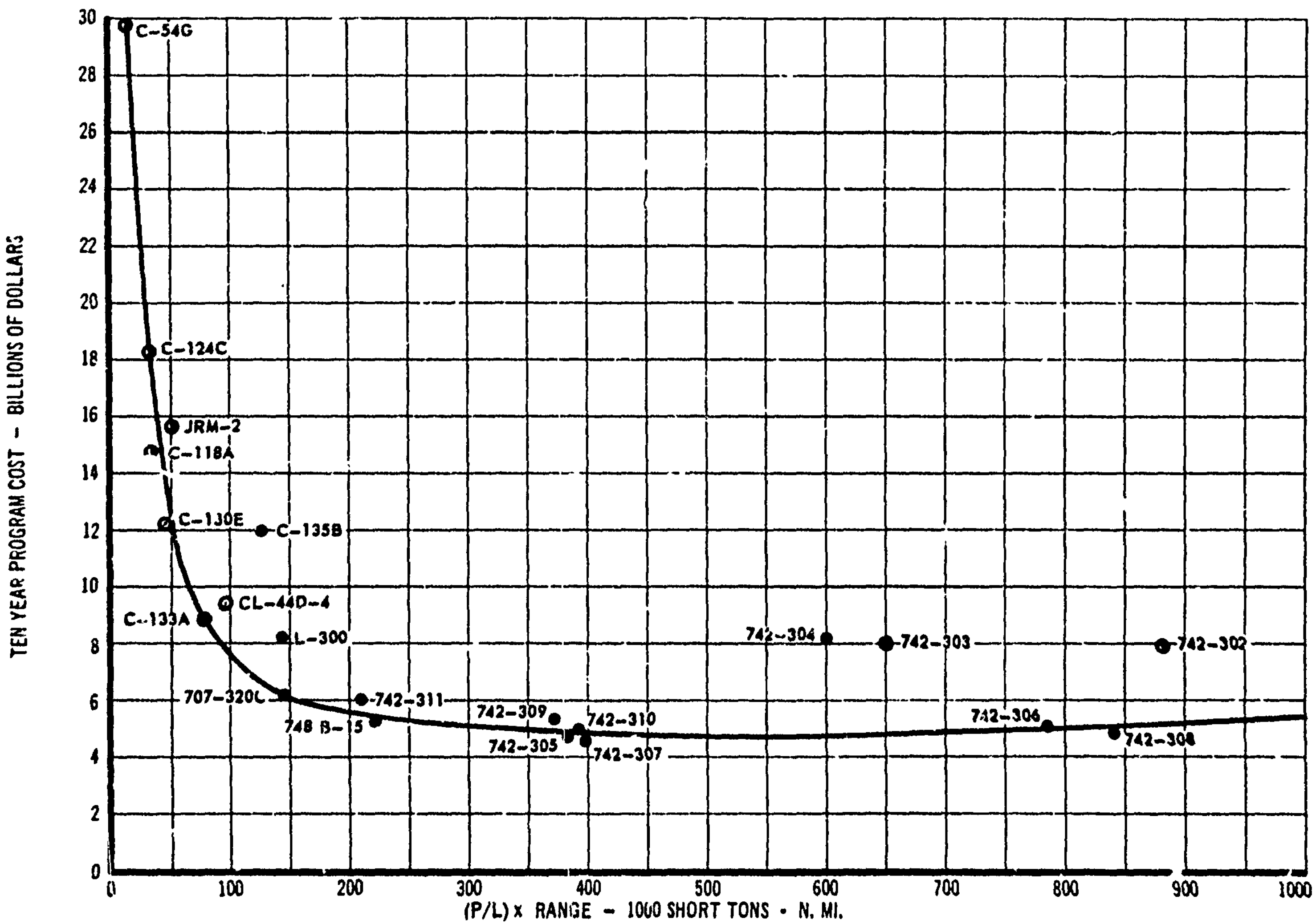


Fig. 107 Ten Year Program Cost versus (P/L) x Range For Aircraft

in Fig. 108 and Table 29. These data are taken from Ref. 50 which explores movement of a large force to the Far East under wartime conditions. Significant to the conclusions of this referenced study and Fig. 108 is the fact that a complete operations research analysis was done and consideration was given to:

(1) destination seaport limitations and congestion.

(2) congestion of ground lines of communication between the port and the area destination.

(3) consideration of an aircraft design which has intercontinental range and forward area landing capability.

(4) consideration of the effect on total cost of the speed of deployment.

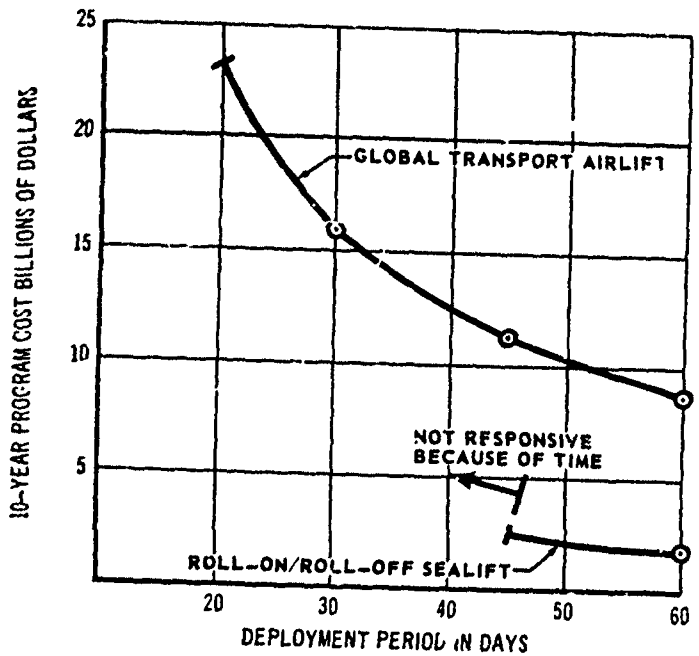


Fig. 108 Cost Comparison for Advanced Capability Aircraft and Roll-on/Roll-off Ships in Wartime Mission

Other missions of Ref. 50 show the difference in program costs for sea and air transport to be even less than indicated in Fig. 108.

Table 29 Effectiveness for Advanced Capability Aircraft and Roll-on/Roll-off Ship in Wartime Mission

DEPLOYMENT CONDITION	AIRCRAFT OR SHIP TYPE	DEPLOYMENT TIME - DAYS					
		10	13	20	30	43	60
DIRECT ROUTE	GLOBAL TRANSPORT	AB	•	•	•	•	•
	RO/RO SHIP	D	D	D	C	•	•

CODE - 1980 Time Period

• - Deployment complete and realistic
A - Number of aircraft exceeds production capability or availability
B - Combat area ground LOC becomes saturated
C - Ship deployment to Bangkok completed but insufficient time for troops to reach combat area.
D - Insufficient time for all ships to reach Bangkok.

6.C CONCLUDING REMARKS AND RECOMMENDATIONS

A significant measure of the worth of a transport vehicle can be obtained by interpreting its relative position on the efficiency plots of Section 3 and the cost plots of Section 5. Because of the complexity and interaction of the vehicle parameters, it is not possible to devise a single presentation to answer the question - which is the best vehicle? However, by comparing in toto the efficiency and cost data and by considering the relative complexity of the designs as related to the operational considerations of Section 4, a satisfactory conclusion can be reached.

Ships, in other studies, have been shown to be an order of magnitude more effective than aircraft in certain areas. This is apparent in some, but not all, of the parameters of this study. So far as can be seen their relative positions will be maintained in the future with a tendency to close the gap as aircraft are improved. The significance of air transport competition to ships, of course, is in their large speed advantage and relative invulnerability to wartime losses. This speed advantage for the airplane is shown for one wartime case in Section 5, Fig. 108 where airlift accomplishes missions not attainable by ships.

The data plots of Section 5.4.4 are most significant for an abbreviated comparison of cargo aircraft. The following points should be observed:

(1) Cruise speed is an important, though not overriding, consideration. Vehicles with higher cruise speeds tend to have lower total program costs. Compressibility drag rise is the limiting factor.

(2) Large payload capacity is equally important. For the cost problem of this study, an aircraft payload of 200,000 to 300,000 lbs offers minimum total program cost, with the largest reduction achieved below 200,000 lbs.

(3) Airplane L/D and engine sfc are the two most important single parameters. Large improvements in either or both can, to

a degree, offset the effects of reduced speed and reduced size. For instance, compare on Figs. 105 and 106 742-302 LOBOY (high L/D, low sfc, low speed) with 742-304 LFC airplane (high L/D, higher speed) and with 742-306 (large size, higher speed).

Not shown explicitly in these curves but presented in the cost assumptions, Table 27, is the effect of airplane cost. Because of the steep (initial) learning curve in the industry, the size of the fleet considered is important to any cost problem. Conclusions can be changed considerably by changing the problem. The mission chosen for this study is typical for these large aircraft but certainly not the only possibility.

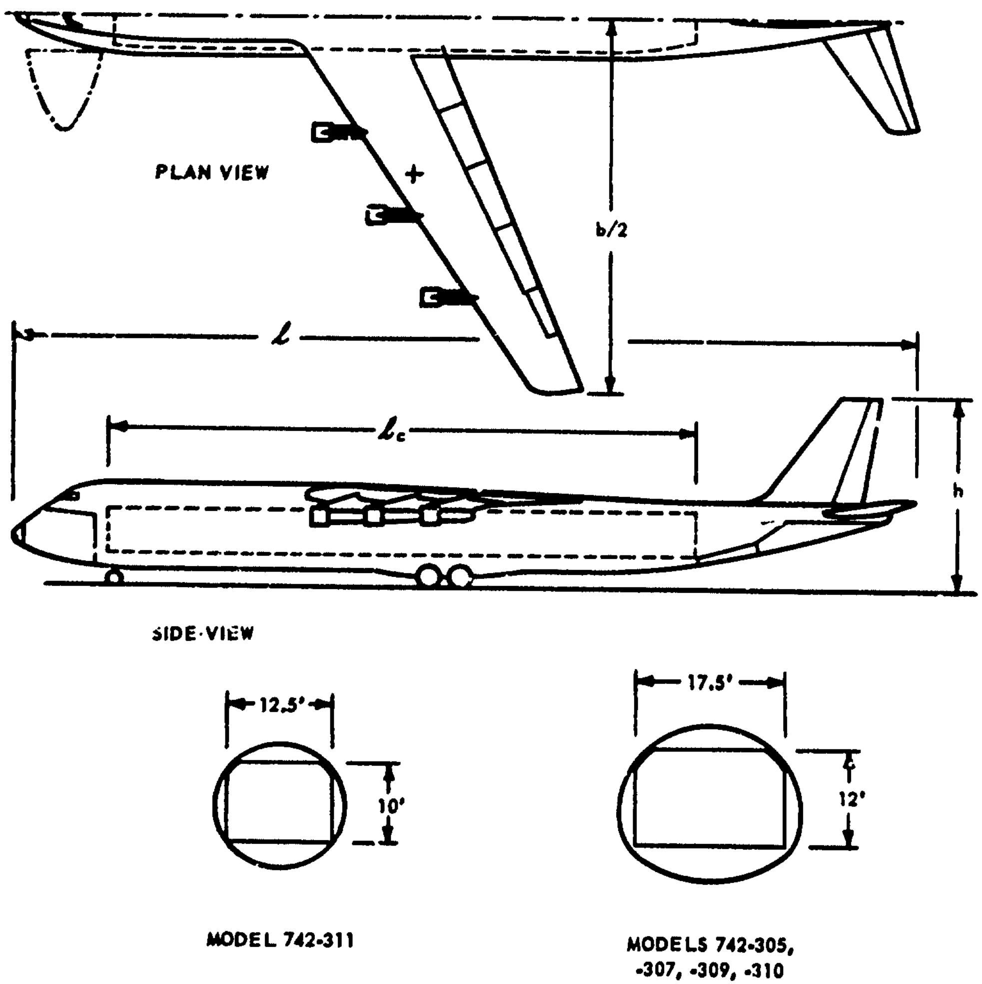
The most promising area for future development appears to be in the powerplant. As always, lighter weight, higher powered engines with lower fuel consumption are highly desirable for both ships and aircraft. Particular interest is seen for the regenerative turbofan aircraft engine of moderately high (10 to 15) bypass ratio.

7.0 APPENDIX I - SUBSTANTIATING DATA FOR VEHICLES DESIGNED IN THIS STUDY

7.1 TRANSPORT AIRCRAFT

Each of the aircraft identified with Boeing Model No. [illegible]2 were designed specifically for this study. Data for Model 748B-15 were taken from one of an early series of design studies completed for the (now) CX-HLS mission. It is included in this study to show the comparison with aircraft designed to other mission requirements.

All study aircraft were completed through the first phase of preliminary design. Three-view layouts were made for each aircraft (Figs. 109 and 110). Drag, weight and balance, and performance estimates are compatible with that stage of development. A summary of the aircraft and their more important characteristics is shown in Table 30.



MODEL 742-	ℓ (FT.)	b (FT.)	h (FT.)	ℓ_c (FT.)
305	233	203	52.1	151
306	289	284	70.3	195
307	233	200	51.3	151
308	289	284	68.3	196
309	225	266	61.0	151
310	225	253	58.5	151
311*	165	148	39.5	100

* (4) ENGINE AIRPLANE

Fig. 109 3 View Drawings For Models 742-305 Through -311

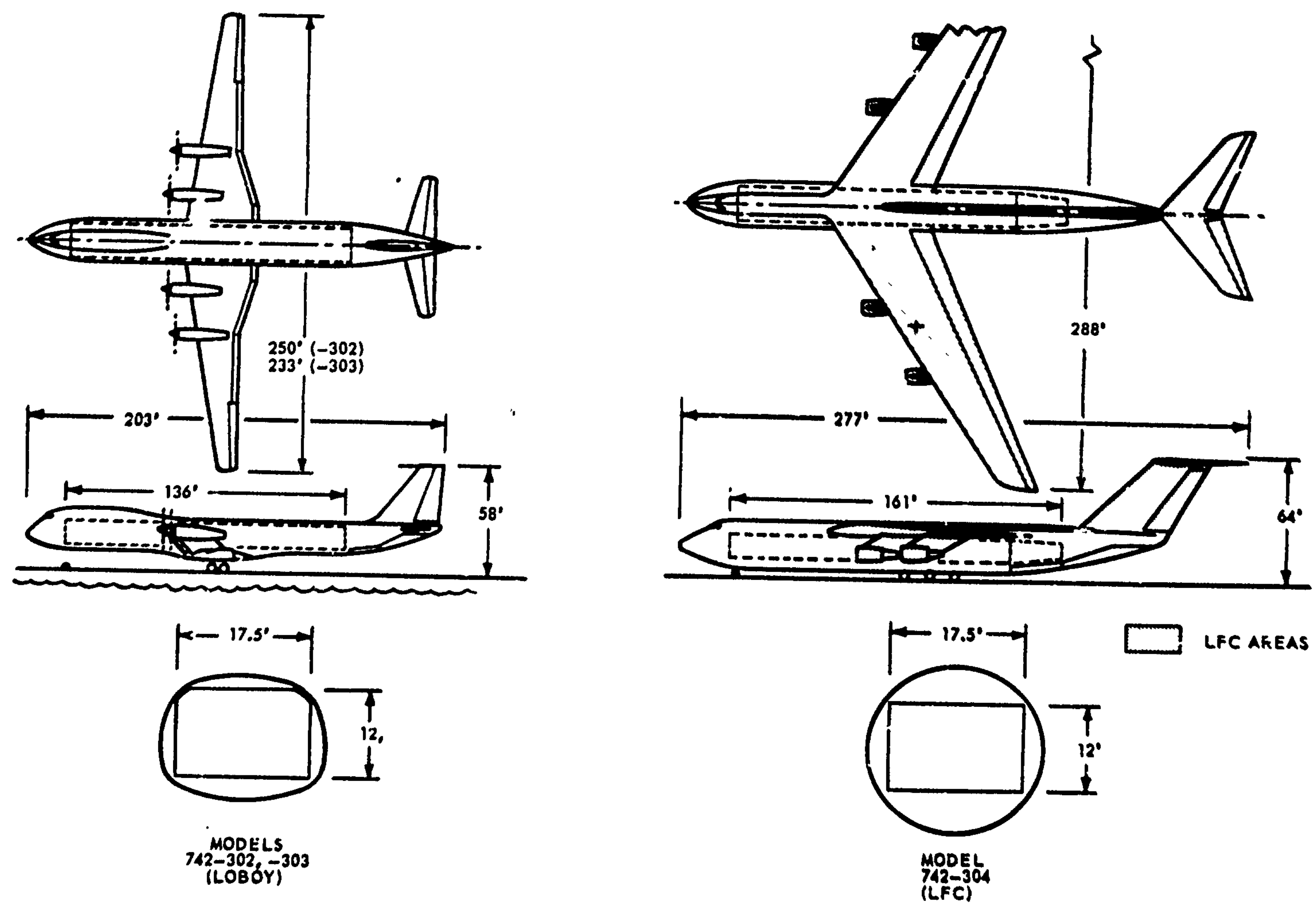


Fig. 110 3 View Drawings For Models 742-302, 303 and 304

Table 30 Aircraft Characteristics

AIRCRAFT	YEAR ENTER SERVICE	DESIGN PAYLOAD	DESIGN GROSS WEIGHT	WING LOADING	WING AREA	WING ASPECT RATIO	1/4 CHORD SWEEP	TAPER RATIO	THRUST LOADING	TYPE ENGINE	NUMBER ENGINES	THRUST PER ENGINE
		LBS	LBS	LBS/SQ FT	SQ FT		DEG					
742-302	1973	200,000	650,000	115.	5630	11.1	7°	.35	---	1	4 T'Prop 3 T'Fan	7300 ESHP 23,000*
742-303	1973	200,000	565,000	116.	4875	11.1	7°	.35	---	1	4 T'Prop 2 T'Fan	7000 ESHP 29,000*
742-304	1973	200,000	830,000	85.	9750	8.5	30°	.35	---	2	4 T'Fan +4 Compressor	41,500* -323*/sec
742-305	1973	200,000	672,000	130.	5170	8.0	30°	.35	5.0	a=3 T'Fan	6	22,400
742-306	1973	400,000	1340,000	130.	10308	8.0	30°	.35	5.0	a=3 T'Fan	6	44,670
742-307	1983	200,000	651,000	130.	5008	8.0	30°	.35	5.0	a=3 T'Fan	6	21,700
742-308	1983	400,000	1310,000	130.	10077	8.0	30°	.35	5.0	a=3 T'Fan	6	43,670
742-309	1973	200,000	650,000	110.	5910	12.0	10°	.38	5.3	a=5 T'Fan	6	20,440
742-310	1983	200,000	588,000	110.	5346	12.0	10°	.38	4.7	a=15 Regen T'Fan	6	20,830
742-311	1973	100,000	356,000	130.	2740	8.0	30°	.35	4.7	a=3 T'Fan	4	18,900
748B-15	1968	160,000	600,000	120.	5000	8.4	35°	.35	4.35	JT3D-8B	6	23,000

1 Cruise: Regen T'Prop
T.O.: Regen T'Prop + T'Fan

2 Bypass Ratio T'Fan + LFC
Bleed and Burn Suction Compressor

AIRCRAFT	DESIGN POINT RANGE	CRUISE MACH NO.	W_{FU}	(L/D) AVE CRUISE	TOTAL AIRPLANE WETTED AREA	AIRPLANE PARASITE AREA	O.W.E.	W_{STRU}	W_{PP}	W_{FE}	W USEFUL LOAD
	N.MI.		LBS		SQ FT	SQ FT	LBS	LBS	LBS	LBS	LBS
742-302	8800	.28	175,000	34.8	27,790	93.0	250,500	173,000	43,000	28,000	6300
742-303	6500	.29	121,100	32.8	25,090	84.2	227,000	155,500	37,900	27,400	6200
742-304	6000	.73	225,000	34.2	[3]	53.5	383,000	312,800	29,700	34,900	5600
742-305	3800	.74	185,400	20.3	25,520	70.7	266,000	211,200	20,800	28,500	5300
742-306	3980	.74	363,600	21.2	46,730	129.0	536,000	442,700	44,[illegible]	40,200	8800
742-307	3960	.73	182,700	20.4	24,840	67.3	248,000	196,500	17,500	28,5[illegible]	5300
742-308	4200	.73	371,700	21.5	45,030	124.0	497,000	410,900	37,100	40,200	8800
742-309	3720	.58	158,400	24.3	29,020	87.9	274,000	217,900	21,000	29,400	5700
742-310	3920	.58	113,400	23.3	26,260	85.2	262,000	199,100	28,000	29,200	5700
742-311	4200	.74	111,900	19.2	13,880	42.2	131,700	96,100	11,300	18,500	3300
748B-15	2785	.77	153,000	16.8	26,950	82.9	270,000	206,000	33,100	28,200	2700

[3] 15,340 sq ft turbulent
25,730 sq ft laminar

The ten aircraft designed for this study form five basic groups:

Group	Model Nos.	Payload	Year
I	742-311	100,000	1973
	-305	200,000	1973
	-306	400,000	1973
II	742-307	200,000	1983
	-308	400,000	1983
III	742-309	200,000	1973
	-310	200,000	1983
IV	742-304 (LFC)	200,000	1973
V	742-302	200,000	1973
	-303 (LOBOY)	200,000	1973

Groups I and II are larger, newer versions of conventional turbofan aircraft. Group II has the more advanced power plant. The effect of airplane size on the efficiency parameters is seen in a comparison of the three aircraft of Group I.

Group III shows the comparative effect of operating at a reduced design cruise speed with engines of higher bypass ratio.

Group IV is the LFC airplane. The wing and tail surfaces are considered to be effectively all laminar. Because of the probable difficulty of achieving even this much laminar area, the fuselage and the wing and tail root areas are considered turbulent.

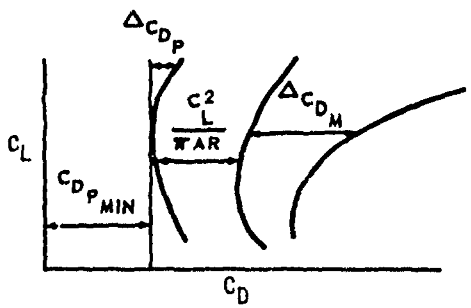
Group V has the two LOBOY aircraft. The low specific fuel consumption of the regenerative turboprop engines and the reduced induced drag of the LOBOY operation combine to make a relatively small aircraft which may be attractive at extremely long ranges. They are assumed to operate at an h/b of about 0.06. A discussion of the operational problems associated with these aircraft is beyond the scope of this study. The data are presented with the reservation that these problems will require solution before LOBOYS are accepted as practical.

Use was made of prior studies in determining all the aircrafts' wing loadings and aspect ratios. It is believed that the geometry shown in Table 30 is reasonable and not greatly different from what would be chosen should a development program be initiated for any one of the vehicles.

7.1.1 DRAG

The drag polar of each aircraft was built up considering each of the polar components where:

$$C_{D_{TOTAL}} = C_{D_{P_{MIN}}} + \Delta C_{D_P} + \frac{C_L^2}{\pi AR} + \Delta C_{D_M}$$



$$C_{D_{P_{MIN}}} = \frac{f_{total}}{S}$$

$$f_{total} = \Sigma\left(C_f \times S_W\right) + \Delta f_{misc}$$

The airplane wetted areas were calculated and a C_f value estimated for each component; i.e., wing, tail, fuselage, nacelle. The sum was found and an increment added, based on information from current airplanes, to account for interference and other miscellaneous items to arrive at the total airplane f.

The items ΔC_{D_P} (that part of the parasite drag coefficient which varies with lift) and ΔC_{D_M} (the increment of drag coefficient which is due to compressibility) were estimated based on information from current airplanes making due allowance for differences in wing geometry. At the cruise condition described in this report both ΔC_{D_P} and ΔC_{D_M} are small. Together they add up to $\Delta C_D \leq .0005$. At other operating conditions they will, of course, be larger. The induced drag term, $C_{D_i} = \frac{C_L^2}{\pi AR}$, is defined in terms of the geometric aspect ratio and the reference wing area.

The polar was used to define the actual drag at each point calculated for the several parts of the mission profile. The parts of the mission are defined in Section 3.2.6.

7.1.2 WEIGHT

The weight for each aircraft was built up by projecting statistical weight data taken from a number of actual airplanes. The basis for the statistical projections included actual group weight statements for the current aircraft of this study. Use was made of data for a number

of other aircraft not included in this study. The weight groups are defined as follows:

Total Structure	Wing Group Horizontal Tail Vertical Tail Body Group Main Landing Gear Nose Gear Nacelle or Eng. Sect.
Total Powerplant	Engine (as installed) Engine Accessories Engine Control Fuel System Starting System Lubricating System
Total Fixed Equipment	Instruments Surface Controls Hydraulic System Electrical System Electronics Furnishings Air Conditioning Anti-Icing
WEIGHT EMPTY	
Useful Load	Crew and Crew Baggage Unusable Fuel Oil and Unusable Oil Emergency Equipment Cargo Equipment Water - Wash & Drink Galley and Contents
OPERATING WEIGHT EMPTY (O.W.E.)	

The O.W.E. and O.W.E. buildup for each aircraft is shown in Table 30. In making these weight estimates the design load factor was set at 2.5 limit for all aircraft except LOBOY, which was set at 2.0.

A problem shared by all who have occasion to compare and interpret aircraft weights is that of understanding what is included in the weight quoted - considerable latitude being taken in defining the weight groups. The weights quoted in this study for all the aircraft are in accord with the definition above. Table 31 has been prepared to further define the quoted weight characteristics of the several aircraft.

Table 31 Design Features Affecting Aircraft Weight

	CARGO HANDLING							OTHER				
Model	Nose Ramp	Tail Ramp	Side Door	Swing Tail	Prov. for Pallets	Air Drop Ramp	High Cap Floor	Overload Capability	High Flotation Gear	High Lift Devices	Prov. for Personnel	Laminar Flow Control
C-54G			x				x				x	
JRM-2			x**								x	
C-116A			x**								x	
C-124C	x*										x	
C-130E		x	x		x	x	x				x	
C-133A		x	x		x		x	x			x	
CL-44D-4			x	x	x		x					
C-135B			x		x			x			x	
707-320C			x		x						x***	
L-300		x			x							
742-302	x	x										
742-303	x	x										
742-304	x	x										x
742-305	x	x										
742-306	x	x										
742-307	x	x										
742-308	x	x										
742-309	x	x										
742-310	x	x										
742-311	x	x										
748B-15	x	x			x	x	x		x	x	x	

* Loading Elevator in Lower Fuselage
** Two Large Side Cargo Doors
*** Complete Facilities for Commercial Passenger Service Except Seats are not Installed

7.1.3 POWERPLANT

Each of the future engines of this study was designed to suit the characteristics of projections to the present state-of-the-art, assuming that sufficient development funding were provided. Data were generated in the form of plots of $sfc/\sqrt{\theta}$ vs F_N/δ for a range of Mach Numbers. Predictions as to basic parameters, such as the optimum engine bypass ratio or compressor pressure ratio and the more detailed parameters, such as engine thrust/weight ratio, T/W_{eng}, were made on the basis of a statistical projection of the latest information available from engine manufacturers. Ref. 2b presents a complete discussion of the engine data used. Table 32 presents a summary of the assumptions on which the future engine data are based.

Table 32 Future Engine Data Assumption

PARAMETER	Used on 742-311 -305 -306	Used on 742-309 -304	Used on 742-307 -308	Used on 742-310	Used on 742-302 -303
Compressor Efficiency (Polytropic)	.91	.91	.92	.92	X
Turbine Efficiency (Adrabatic)	.92	.92	.93	.93	X
Fan Efficiency (Adrabatic)	.88	.88	.90	.87	X
Regenerator Effectiveness	---	---	---	.81	X
Overall Pressure Ratio (at Sea Level Static)	20	20	24	8	8
Fan Pressure Ratio (at Sea Level Static)	1.8	1.55	1.9	1.2	X
Bypass Ratio	3	5	3	15	--
Turbine Inlet Temperature (at Sea Level Static)	2500°R	2500°R	2700°R	2500°R	2500°R

X This parameter was not defined explicitly in the performance prediction of this engine.

7.2 TRANSPORT SHIPS

Four advanced transport ships were designed for this study (Table 33). They are defined as a 1975 conventional ship (742-320S) and a 1985 conventional ship (742-321S). Also shown are nuclear powered versions of these ships. These are identified, respectively, as 742-320S Nuc and 742-321S Nuc.

Detail used in determining these advanced ships compares with that for the future aircraft. Ship design is characterized by standardized determination of design coefficients associated with hull form and ship speed capability and by the conservatism apparent in ship designers' projections to current state-of-the-art.

These factors were taken into account in making these advanced ship preliminary designs. Ref. 26 treats this in detail and defines the data assumptions that were made.

In addition, data are also presented for 742-322S, a large hydrofoil ship designed for 1975 operation. Ref. 26 summarizes and discusses the design characteristics of 742-322S. As discussed in Section 2.1.4, the hydrofoil ship is not an intercontinental transport ship in the same sense as the 742-320S and 742-321S. It is included in this section to avoid an additional section of substantiating data.

Table 33 Design Data For Advanced Marine Vehicles

SHIP	YEAR ENTER SERVICE	DESIGN P/L (L.T.)	GROSS WEIGHT (L.T)	LENGTH BETWEEN PERP. (FT)	TYPE ENGINE	NO. PROPELLERS	NORMAL SHP	DESIGN SEA SPEED (KNOT)	CRUISING RANGE (N. MI.)	L/D	OWE (L.T.)	WEIGHT STEEL (L.T.)	WEIGHT MACH. (L.T.)	WEIGHT OUTFIT (L.T.)
742-320S	1975	13158	24000	598	STEAM TURBINE	1	24000	23.5	13000	230	9932	5570	1380	2235
742-321S	1985	20665	45000	750	STEAM TURBINE	2	66000	25.0	13000	175	22115	14400	3200	3290
742-320S NUC	1975	14288	24000	598	NUCLEAR STEAM	1	24000	23.5	400000	230	9712	5570	1380	2235
742-321S NUC	1985	23425	45000	750	NUCLEAR STEAM	2	66000	25.0	400000	175	21575	14400	3200	3290
742-322S	1970	423.7	1060	235	GAS TURBINE	2	24200	40.0	1000	18.5	488.4	296	106	64

8.0 APPENDIX II SUBSTANTIATING DATA FOR COST MODELS

8.1 MILITARY AIR TRANSPORT COSTING METHOD

Total Ten Year Program Costs, for the various fleets of aircraft considered in this study, are tabulated in Table 34. The method used to estimate these costs is presented following the tabulation.

8.1.1 INTRODUCTION

The total program cost of an air transport system consists of the expenditures required for Design Development, Test, and Evaluation (DDT&E), the Initial Investment Cost, and Operating and Main-

Table 34 Total Program Costs For Aircraft Fleets (Billions of 1964 Dollars)

AIRCRAFT	WEIGHT LIMITED PAYLOADS						SPACE LIMITED PAYLOADS FOR DEPLOYMENT OF ARMORED DIVISIONS UTILIZATION = 8 HRS/DAY	
	UTILIZATION = 6 HRS/DAY		UTILIZATION = 8 HRS/DAY		UTILIZATION = 14 HRS/DAY			
	U.E.*	TOTAL Program Cost	U.E.*	TOTAL Program Cost	U.E.*	TOTAL Program Cost	U.E.*	TOTAL Program Cost
JRM-2	1964	32.412	1473	24.764	842	14.818	1003	17.370
C-54G	6323	64.019	4742	49.067	2710	28.601	3055	32.101
C-124C	1680	33.209	1260	25.244	720	14.846	388	18.102
C-118A	2124	28.972	1593	21.945	910	12.800	1181	16.457
C-133A	652	16.785	489	12.815	279	7.587	331	8.097
C-130E	1123	19.907	842	15.134	481	8.906	672	12.224
CL-44D4	616	12.128	462	9.218	264	5.415	522	10.356
C-135B	340	8.971	255	6.820	146	4.014	254	6.794
707-320C	296	9.455	222	7.227	127	4.301	213	6.955
L-300	351	11.262	263	8.581	150	5.099	250	8.254
742-302	329	15.076	247	11.742	141	7.250	154	7.895
-303	348	15.524	261	12.012	149	7.378	163	7.941
-304	152	13.269	114	10.583	65	6.977	81	6.138
-305	149	8.468	112	6.617	64	4.167	76	4.779
-306	75	8.487	56	6.850	32	4.629	37	5.093
-307	149	8.119	112	6.354	64	3.985	76	4.580
-308	76	8.094	57	6.468	33	4.381	38	4.826
-309	187	9.659	140	7.517	80	4.689	93	5.308
-310	185	9.077	139	7.079	79	4.388	92	4.993
-311	296	9.719	222	7.444	127	4.530	175	6.010
748B-15	180	9.917	135	7.704	77	4.777	88	5.357

* Number of unit equipment aircraft

tenance Costs for a given period of time. These expenditures are given in 1964 dollars in this study.

The fleet size required to perform any given deployment task is dependent upon wartime utiliza-tion, mission profile, and the capability and characteristics of the particular aircraft considered. However, the cost involved in performing the wartime mission is not calculated because the significant budget considerations are peacetime costs for a wartime capability. Also, the costs of a major war are indeterminate because of size, length and loca-tion considerations. Occasional limited wars may cost little compared to the year-in year-out costs of peacetime preparedness. The program cost represents the expenditures of acquiring the desired force and operating and maintaining it over a given time period (usually ten years for MATS) under peacetime conditions.

Costing technology is based on the assumption that only one air transport wing will be accommodated per base. Therefore, the total program cost is simply the product of the cost per base including aircraft, times the number of bases required for the proposed fleet.

8.1.2 PROGRAM COST

There are four basic definitions of program cost. The choice of one over another depends on how the data are to be used.

MARGINAL COSTING

Marginal costing is used for planning purposes. Basically, it is a means of comparing alternate systems by considering only cost elements which can be affected by future decisions. Sunk or committed costs are ignored. DDT&E is charged to the year of program go-ahead. Initial investment is spread uniformly over the usefull life of an aircraft. For example, if the program go-ahead for a particular transport system is 1964, first delivery in 1968, last delivery in 1972, and the time period ends in 1977, only the first year delivery aircraft will have served their 10-year useful life. Therefore, for aircraft delivered in 1972, only 5/10 of the initial investment and five years of operation and

maintenance costs may be included in the marginal program cost.

PROGRAM COSTING BY TOTAL OBLIGATIONAL AUTHORITY (TOA)

This type of program cost involves the total government obligation, by fiscal year, that is required to procure, operate and maintain a given fleet size. For example, on a program go-ahead, DDT&E funds are initially required followed by, or concurrent with, initial investment funds for procurement of aircraft and military bases. As aircraft are delivered, annual O&M funds must also be made available to operate the system. The total program cost is then the sum of funds required each fiscal year for the duration of the program. The funding requirements of competitive transport systems can be compared year ' year or by the sum of TOA's starting with initial funding and continuing for a period consistent with the first line life of the transport system.

TOA represents the required funds regardless of when they are authorized, appropriated, or expended. This type of cost breakdown is used by the DOD for program change proposal comparisons.

NEW OBLIGATIONAL AUTHORITY

Another approach to program costing is that used for authorizing the DOD program packages. The funds necessary for DDT&E, procurement of a specified whole number of aircraft plus spares, or annual operation and maintenance cost for a given fleet must be provided for, in advance, by a new obligational authority. This new obligational authority is defined as the full cost of an increment of a program (e.g., DDT&E or a production contract for sixteen aircraft) regardless of the year in which the funds are expended.

TEN YEAR PROGRAM COST

A short-cut method is sometimes used to compare the relative costs of transport systems. The Ten Year Program Cost is the sum of funds required for DDT&E, Initial Investment and 10 years of O&M for the total number of U.E. aircraft considered for equal capability for each transport system

in the comparison study. This method is used for this study.

8.1.3 INITIAL INVESTMENT COST

Program costing can ' ; categorically divided into two major components, Initial Investment Cost and Annual Operation and Maintenance cost.

The Initial Investment cost consists basically, of two parts: (1) cost for procurement of the required aircraft fleet including spares, and (2) costs for initially establishing a military base of operation.

Aircraft directly involved in performing a given mission are called unit equipment (U.E.) aircraft. To enable a Command to maintain its basic U.E. inventory, additional aircraft (command support) are authorized. In addition to command support aircraft, advanced aircraft purchases are necessary to account for attrition losses. The total production quantity then represents all U.E., command support and attrition aircraft. The unit cost of an airplane is based on the total production quantity and does not include DDT&E.

The cost of the base includes construction of runways, facilities, training of flight crews and ground personnel, aerospace ground equipment, stocks of petroleum, oil and lubricants (POL) and various other miscellaneous items. Existing bases will be inherited and therefore no cost for modifying or expanding a base, is considered.

A sample calculation of initial investment cost is shown in Table 35. Each cost item is explained on the following pages.

INITIAL INVESTMENT COSTS

- BASIC AIRCRAFT

  Basic aircraft represents the total cost of all U.E. aircraft on base. The unit cost of new aircraft is developed by the same type of detailed cost estimates that are used to cost aircraft proposals. The aircraft cost is based on the

Table 35 Initial Investment Cost

INITIAL INVESTMENT COST — AIRPLANE MODEL 742-308	
COST BASED ON PRODUCTION OF 71 A/C - 67 U.E. — ENGINE MODEL	
C_t = TOTAL COST OF AIRPLANE = 23,655,000; W_E = WEIGHT EMPTY = 488,200	
C_e = COST OF ONE ENGINE = 750,000; W_r = WEIGHT OF ELECTRONICS = 3,250	
N_e = NO. ENGINES/AIRPLANE = 6; N_w = NO. AIRPLANES/WING = $\boxed{48}$	
C_r = COST OF ELECTRONICS = 200,000; F_c = FUEL BURNED GAL/HR = 5,702	
C_{af} = $C_t - C_eN_e - C_r$ = 18,955,000; C_f = FUEL COST $/GAL = .10	
U = YEARLY UTILIZATION HRS = 1,825; R_a = ATTRITION RATE = .00001	
A. BASIC AIRCRAFT	
$I_{UE} = C_t N_w$	1135.4
B. COMMAND SUPPORT	
$I_{CS} = .10\, I_{UE}$	113.5
C. ADVANCED ATTRITION BUY	
$I_{AAB} = .75\, R_a\, U\, I_{UE}$ (Program Years)	155.4
D. MAINTENANCE SPARES	
Airframe $I_{af} = C_{af} N_w$ (Curve Value)	54.6
Electronics $I_r = C_r N_w$ (Curve Value)	2.2
Engines $I_e = C_e N_e N_w$ (Curve Value)	113.0
E. PERSONNEL TRAINING (Assuming 50% Inherited)	
I_{PT} = .50 ($70,000 Pilots + $42,000 Nav. + $10,000 Non-Crew Off.	43.4
+ $4,000 Airm.)	
F. TRANSPORTATION	
I_T = $78 Mil. Pers. + $697 Off. + $435 Airm. + $481 Civ.	6.3
G. BASE - NEW OR ADDITIONAL CONSTRUCTION (50% for Tenant)	
I_{BNEW} = $10M + ($3000 Total Base Pers.) + ($3 W_E x N_w)	-----
H. AEROSPACE GROUND EQUIPMENT - AGE	
I_{AGE} = $312 Total Base Pers. + .064 I_B	13.0
I. STOCKS P.O.L.	
I_{POL} = .065 Annual P.O.L.	4.2
J. NON AIRCRAFT SUPPLY	
I_{NAS} = $176 Total Base Pers.	2.8
K. WAR RESERVE	
$I_{WR} = (.01\, C_{af} + .06\, C_e N_e + .12\, C_r)\, N_w$	-----
TOTAL INITIAL INVESTMENT COST (IN MILLIONS) PER WING	1645.8
TOTAL INITIAL INVESTMENT COST (IN MILLIONS), TOTAL FLEET = 1645.8 $\frac{57}{48}$	1954.4

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total production cost excluding DDT&E.

- **COMMAND SUPPORT**

  Command support is estimated at ten percent of the basic aircraft and represents additional aircraft authorized to a command to enable it to maintain the basic inventory.

- **ADVANCED ATTRITION BUY**

  This cost is dependent on the peacetime attrition rate, unit cost of aircraft, annual utilization and the assumed program years. The attrition rates usually are taken from the "Planning Factors Manual" (AFM 172-3).

- **MAINTENANCE SPARES**

  Initial spares are shown separately for airframe, electronics and engines. They are based on the average daily utilization and are estimated as a percentage of the corresponding initial cost in the basic aircraft. (See Fig. 111).

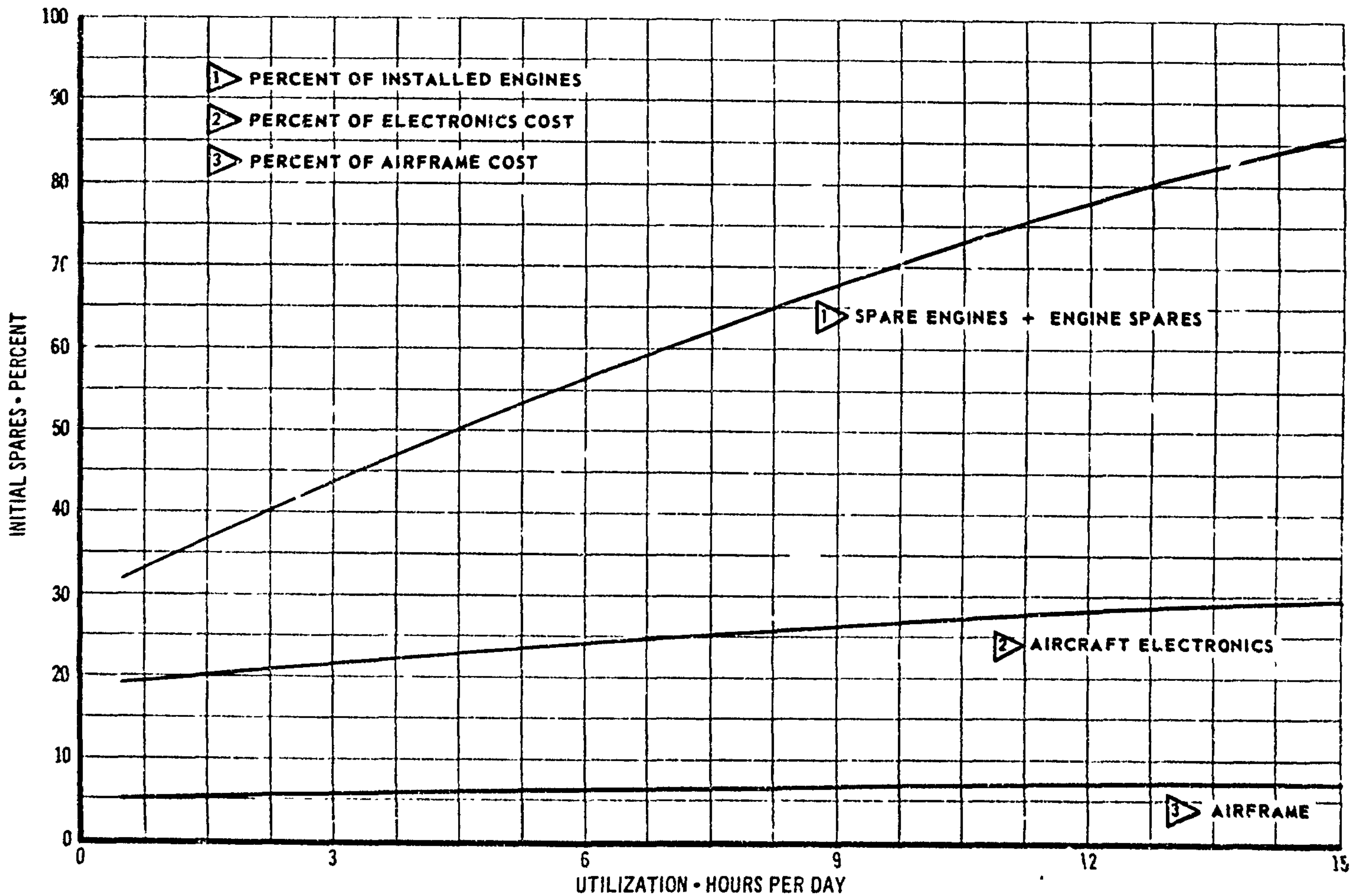

Fig. 111 Aircraft Initial Spares Transport Systems

- PERSONNEL TRAINING

  This category includes the cost necessary to train military personnel as required for the transport system. This cost is determined by multiplying the number of pilots, navigators, non-crew officers and airmen by a respective average training cost as given in the "Peacetime Planning Factors Manual". Half of these expenses are assumed to be inherited.

- TRANSPORTATION

  This item includes the cost of transporting military and civilian personnel, their dependents and household goods, and organization equipment. The factors used to compute these costs have been developed from the "Planning Factors Manual" and are directly related to the number of officers and airmen.

- BASE - NEW OR ADDITIONAL CONSTRUCTION

  Base facilities costs were developed from the 1956 "Peacetime Planning Factors Manual" for a non-tenant organization. Broken down into three factors, they consist of a basic amount for an entire airplane wing (basic amount $\leq$ other two factors combined), a cost per man on base, plus a dollar per pound rate of aircraft weight empty times the number of U.E. airplanes. If an existing base can be inherited, this cost item will include allowance for the expansion of the base only.

- AEROSPACE GROUND EQUIPMENT (AGE)

  This section includes all initial equipment except aircraft, aircraft spares and spare parts. AGE costs are assumed to be proportional to the number of base personnel and the cost for aircraft and personnel facilities.

- STOCKS POL (PETROLEUM, OIL AND LUBRICANTS)

  This item represents a reserve supply of POL for aircraft and ground equipment requirements. The cost is estimated as a percentage of annual POL.

estimated as a percentage of annual POL.

- NON-AIRCRAFT SUPPLIES
  Non-aircraft supply costs are based on an average peacetime consumption and are proportional to the number of base personnel.

- WAR RESERVE
  War reserve costs consists of spare parts for items such as airframes, engines, electronic systems, photographic equipment, fire control and bombing systems, etc., and are shown as percentages of the corresponding initial cost. Normally, war reserves do not apply to MATS transport systems.

8.1.4 OPERATION AND MAINTENANCE COSTS

Operation and Maintenance (O&M) costs represent expenditures directly connected with the peacetime operation and maintenance of a transport wing. Specifically, O&M costs include the cost of maintenance material (i.e., airframe spares, electronic equipment spares and engine spares), depot labor, personnel pay and allowances, replacement training and personnel transportation, base maintenance, aircraft POL and other miscellaneous expenses. Each of these items is explained on the following pages.

Table 36 shows a sample calculation of annual O&M costs for a 48 U.E. transport wing. The calculation sheet is set up to generate the cost of one wing per base. To determine the annual O&M cost for a given fleet, the cost per base is multiplied by the ratio of U.E. aircraft available each year to the number of U.E. aircraft stationed on one base. The total O&M for the fleet during a programmed time period would be the sum of all annual expenditures during that period.

Table 36 Annual Operations and Maintenance Costs

ANNUAL OPERATIONS AND MAINTENANCE COSTS	AIRPLANE MODEL 742-308
	ENGINE MODEL
C_t = TOTAL COST OF AIRPLANE = 23,655,000	W_E = WEIGHT EMPTY = 488,200
C_e = COST OF ONE ENGINE = 750,000	W_r = WEIGHT OF ELECTRONICS = 3,250
N_e = NO. ENGINES/AIRPLANE = 6	N_w = NO. AIRPLANES/WING = $\boxed{48}$
C_r = COST OF ELECTRONICS = 200,000	F_c = FUEL BURNED GAL/HR = 5,702
$C_{af} = C_t - C_e N_e - C_r$ = 18,955,000	C_f = FUEL COST \$/GAL = .10
U = YEARLY UTILIZATION HRS = 1,825	

A. MAINTENANCE MATERIAL	
Airframe $A_{af} = .00002\ C_{af}\ U\ N_w$	33.2
Electronics $A_r = .00010\ C_r\ U\ N_w$	1.8
Engines $A_e = .00015\ C_e N_e\ U\ N_w$	59.1
Depot Labor A_{DL} = BASE MAINT. LABOR = \$4500 MAINT. PERS.	24.5
B. PERSONNEL PAY & ALLOWANCES	
$A_{P_{MATS}}$ = \$10,400 Pilots + \$10,100 Nav. + \$11,200 Non-Crew Off.	77.2
+ \$4,100 Airm. + \$6000 Civ.	
$A_{P_{SAC}}$ = \$13,500 Pilots + \$12,600 Nav. + \$10,100 Non-Crew Off.	
+ \$4,100 Airm. + \$6000 Civ.	
C. REPLACEMENT TRAINING AND PERSONNEL TRANSPORTATION	
A_{TR} = \$4250 Pilots + \$2570 Nav. + \$1830 Non-Crew Off. + \$880 Airm.	13.4
D. BASE MAINTENANCE	
$A_B = .05\ I_B$	0.4
E. AIRCRAFT P.O.L.	
$A_{POL} = F_c\ C_f\ U\ N_w$	49.9
F. MISCELLANEOUS COSTS	
A_M = \$.70M + (\$506 Total Base Pers.) + (14 W E N_w)	11.9
TOTAL ANNUAL OPERATIONS AND MAINTENANCE COSTS (IN MILLIONS) PER WING	277.4

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However, the O&M cost is not entirely allocated to the MATS budget. A portion of it is recovered through industrial fund revenues. They are defined as the income received by MATS for services rendered to the various branches of the armed forces.

Table 37 shows the factors that have to be applied to the O&M costs to estimate industrial fund revenues. Since they are not a part of the MATS budget, they have to be excluded from the O&M cost in all studies dealing with the MATS portion of the DOD budget only.

ANNUAL OPERATIONS AND MAINTENANCE COSTS

- MAINTENANCE MATERIALS

  This item consists of annual aircraft materials used at the base and the depot plus the depot labor. The costs are estimated in four categories: Airframe, electronics and engine material, and depot labor. Maintenance material for airframe, electronics and engines are related

to actual flying hours. Depot labor costs are assumed to be equal to the cost of base maintenance personnel.

- PERSONNEL PAY AND ALLOWANCES

Personnel pay and allowances are based upon standard rates listed in the Planning Factors Manual. The following elements of pay are taken into consideration in deriving a weighted average for MATS personnel: Basic pay, quarters allowances, subsistence allowance, clothing allowance, flight pay, incentive pay and other payments such as re-enlistment bonuses, death gratuities, etc. The manpower requirements, as listed on the personnel calculation sheet Table 38, were derived from actual Air Force unit manning documents.

- REPLACEMENT TRAINING AND PERSONNEL TRANSPORTATION

Average annual turnover rates (Planning Factors Manual) were applied to the initial investment cost for personnel training and transportation to determine both expenses.

- BASE MAINTENANCE

Annual base maintenance is assumed to be 5 percent of the initial aircraft and personnel facility costs.

- AIRCRAFT POL (PETROL, OIL AND LUBRICANTS

The annual POL costs are defined as the total fuel and lubricants consumed by the basic wing aircraft operating for one year times the average cost per gallon.

- MISCELLANEOUS COSTS

This includes all miscellaneous costs not contained in previous items such as POL for ground equipment, heating oil, medical supplies, the cost of the director of supply and services support in Air Material Command, etc. It is assumed to be a function of the number of base personnel and the

weight empty of the aircraft plus a constant based on a full airplane wing (constant ≐ other two factors combined) and has been developed from RAND Corporation data.

8.1.5 INDUSTRIAL FUNDING

The Industrial Fund is made up of the following items and allows the percentage of cost shown for each item.

Table 37 Factors to O & M Costs to Estimate Industrial Fund Revenues

	PERCENT OF OPERATION AND MAINTENANCE
Maintenance Material	
Airframe	70
Electronics	85
Engines	85
Depot Labor	80
Personnel Pay and Allowances (Civilians Only)	50
Personnel Transportation (Excluding Replacement Training) $47 Pilots + $47 Nav. + $132 Non-Crew Off. + $97 Airm.	50
Base Maintenance	50
Aircraft POL	100
Miscellaneous Costs	80

8.1.6 PERSONNEL REQUIREMENTS

A method has been developed to estimate manpower requirements for any present or proposed air transport systems. Data from Air Force unit manning documents (UMD's) were used to generate the personnel curves shown on Figs. 112 through 116.

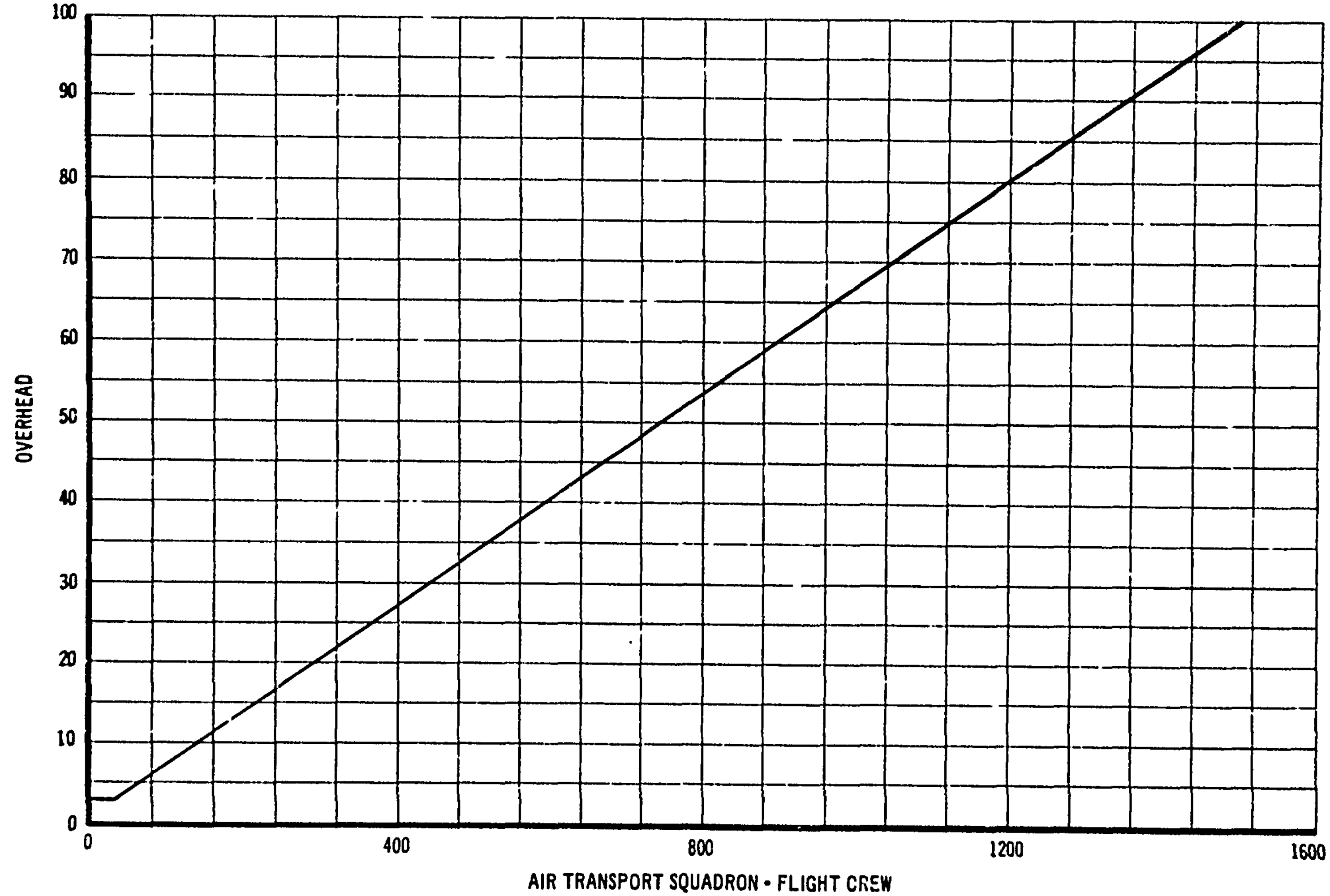

Fig. 112 Air Transport Squadron Overhead Transport Systems

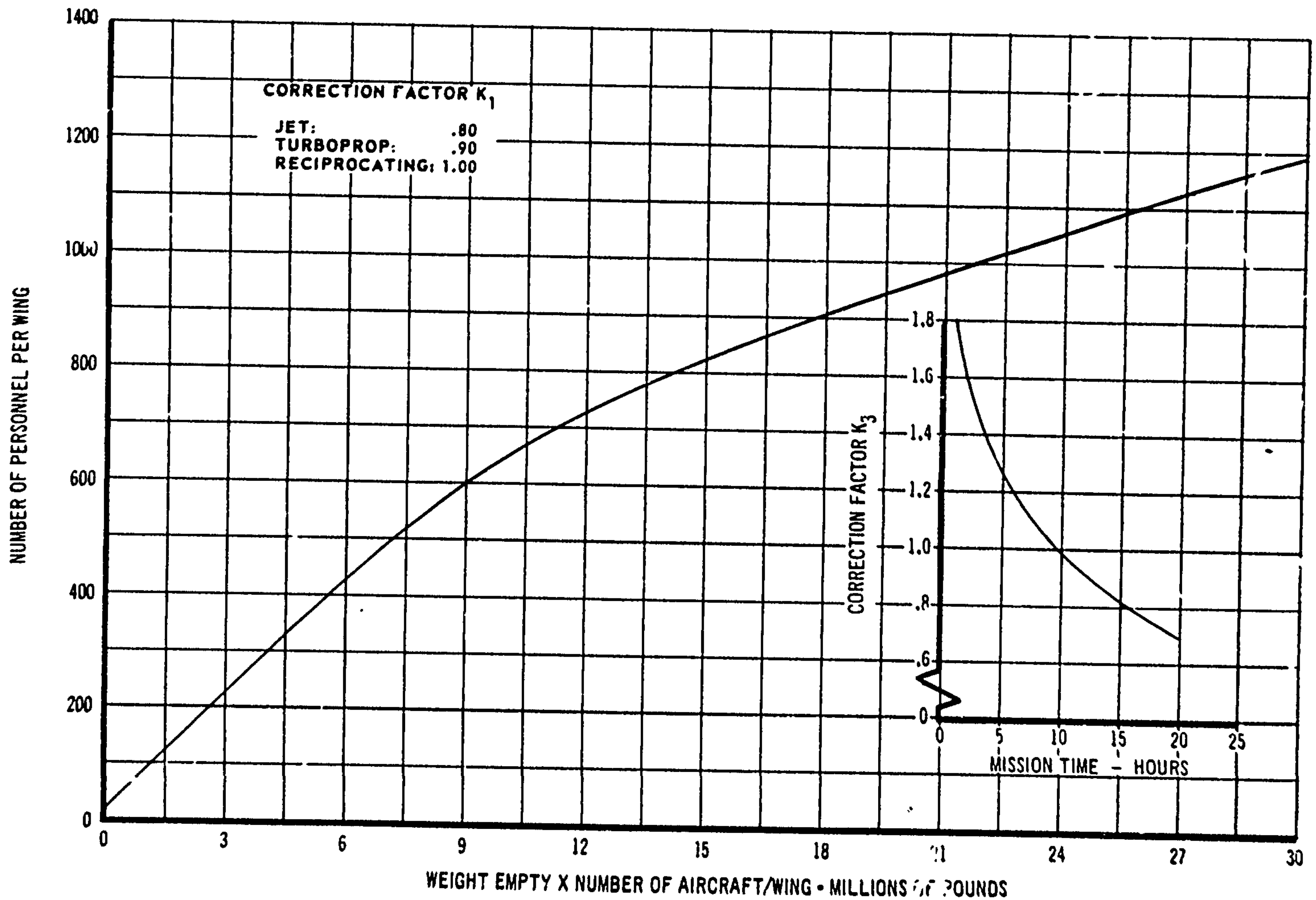

***Fig. 113** Organizational Maintenance – Flight Line Maintenance Squadron – Transport Systems*

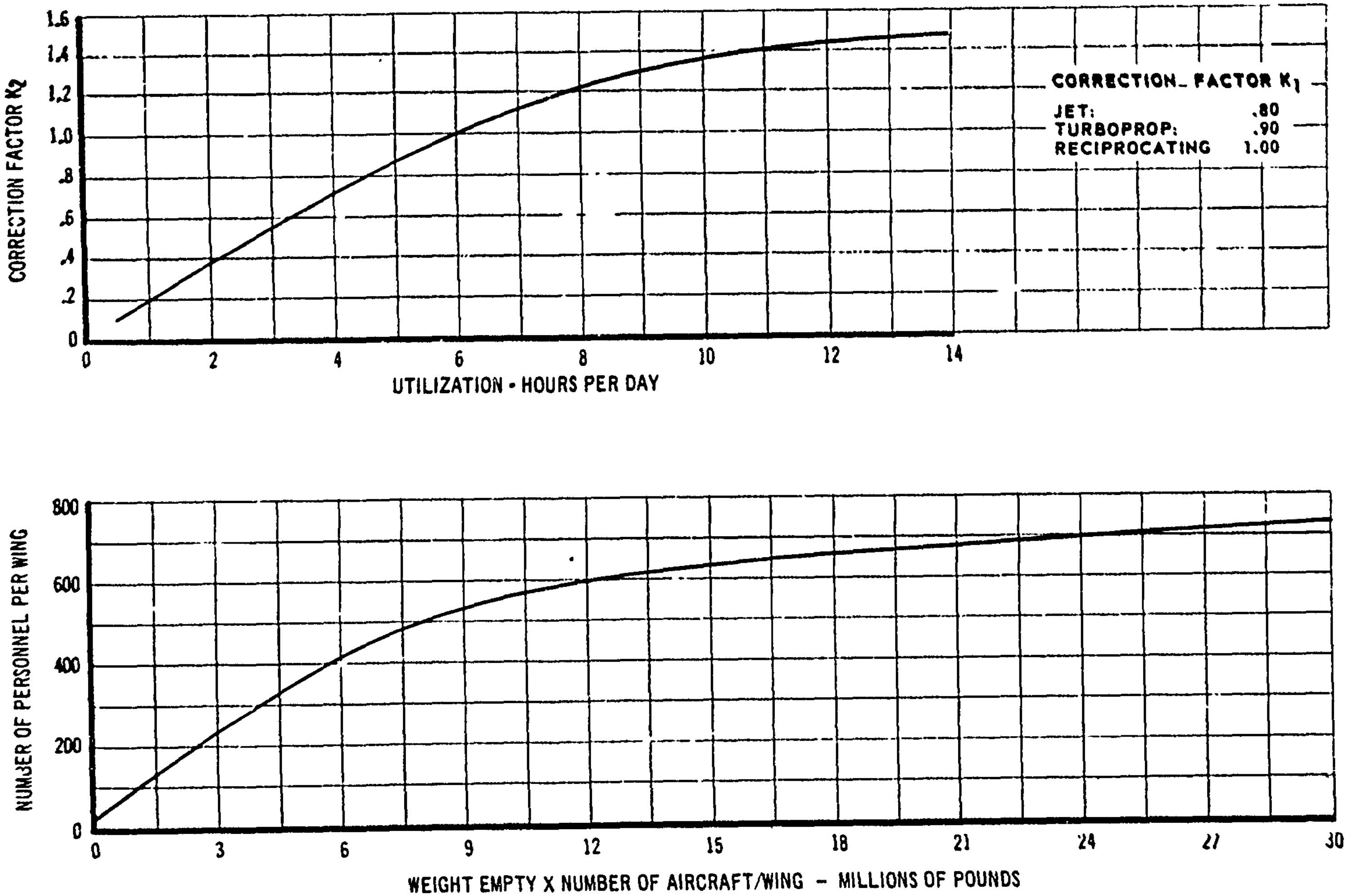

Fig. 114 Organizational Maintenance – Period Maintenance Squadron – Transport Systems

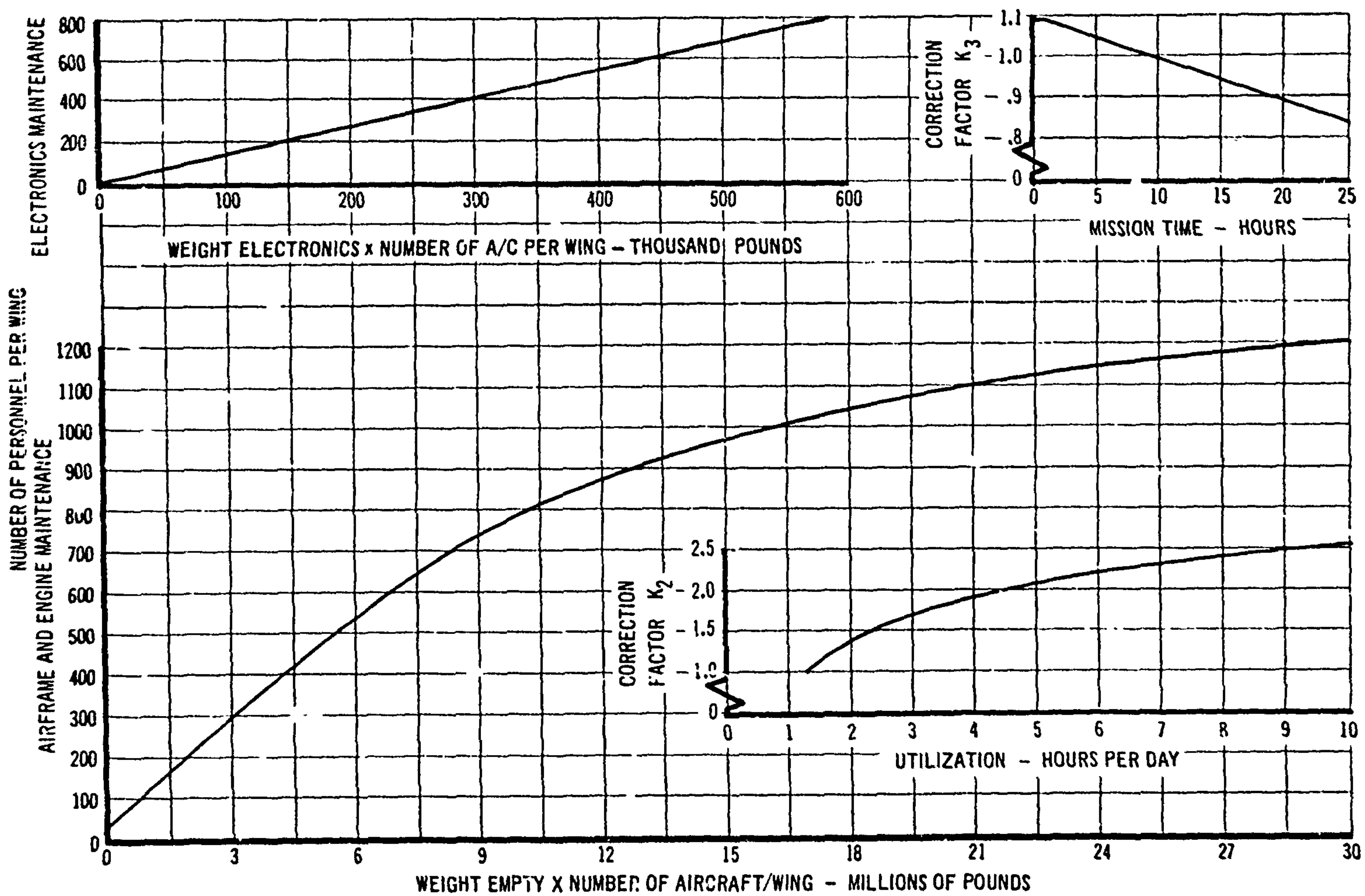

Fig. 115 Field Maintenance Squadron – Transport Systems

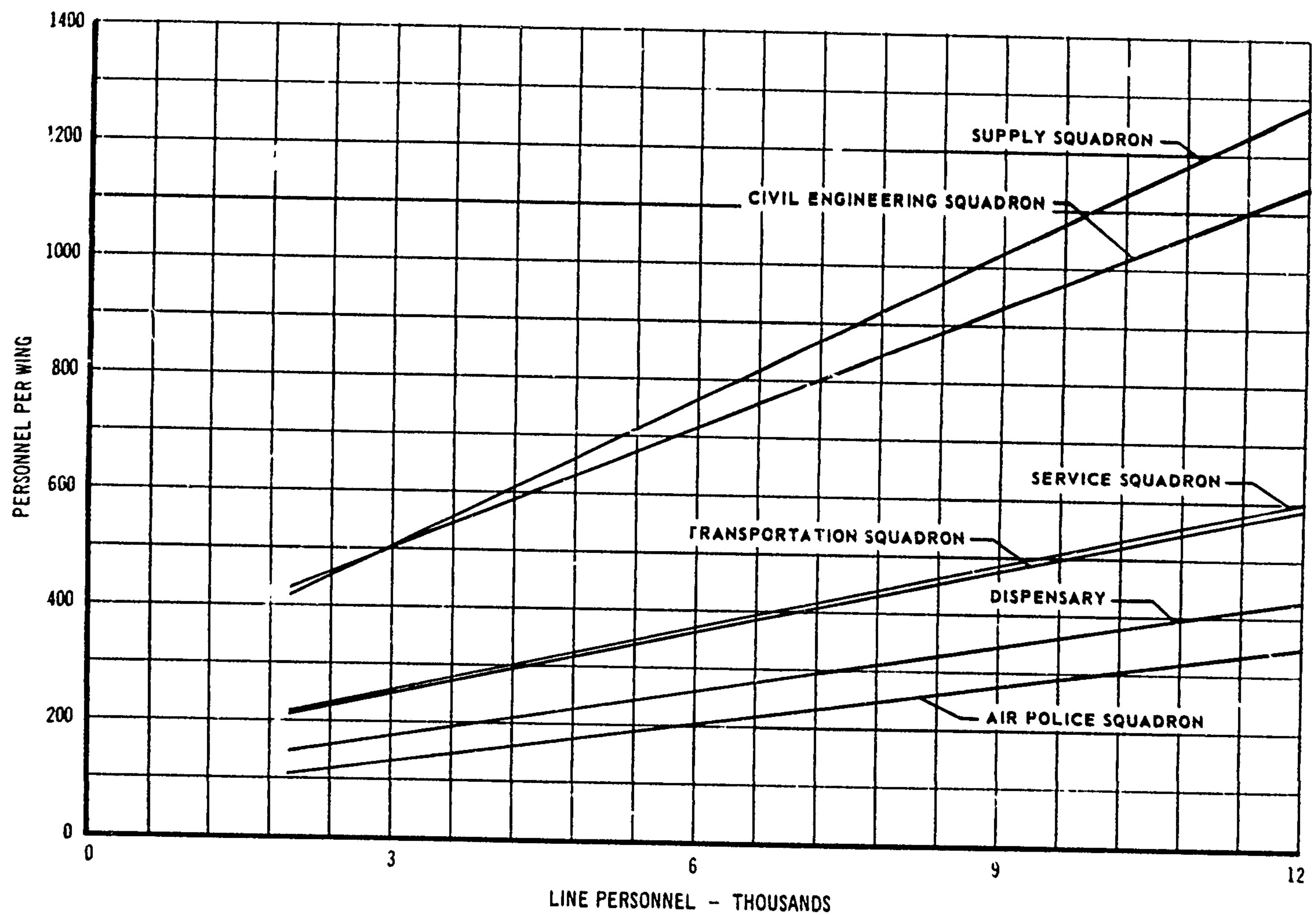

Fig. 116 Service Squadrons – Transport Systems

The number of base personnel required for an air transport system is a function of the aircraft size and type, average mission length, and average utilization. Correction factors were added to allow for variations in mission time, utilization and aircraft type (i.e., reciprocating, turboprop, or jet). Flight crew compositions and crew ratios are determined from actual UMD's or are based on data compiled in Air Force Manual Manpower Policies and Criteria (AFM 26-1).

Table 38 shows a sample calculation of the base personnel required for a 48 U.E. transport wing.

8.2 MILITARY SEA TRANSPORT COSTING METHOD

Total Ten Year Program Costs for the various fleets of ships considered in this study are tabulated in Table 39. The method used to estimate these costs is presented in the pages following the tabulation.

8.2.1 INTRODUCTION

The total program cost for a sea transport system consists of the expenditures required for Initial Cost and Annual Operating Expense for a given time period. These expenditures are given

Table 38 Transport Systems Personnel Per Wing Non-Tenant

MISSION TIME 5.45 HRS
UTILIZATION 5 HRS/DAY
PAYLOAD 200 TONS
BLOCK SPEED 404 KNOTS

AIRPLANE MODEL 742-300
ENGINE MODEL

a.	Air Transport Squadron		
	Flight Crew = No. of Men/Crew x Crews/Airpl. x Nw		868
	Overhead = Curve Value		66
b.	Organizational Maintenance Squadron		
	Flight Line Maint.	= Curve Value ($K_1 \times K_3$)	1027
	Periodic Maint.	= Curve Value ($K_1 \times K_2$)	483
c.	Field Maintenance Squadron		
	Airframe + Engine Maint.	= Curve Value ($K_2 \times K_3$)	3471
	Comm. + Electr. Maint.	= Curve Value ($K_2 \times K_3$)	479
d.	Maintenance Hdq. Sqdn.	= 14% of (b + c)	624
e.	Base Flight Squadron	= 8% of (b + c)	357
f.	Air Terminal Squadron	= (Max. Payload ÷ 1000) x Block Speed x Nw	3878
g.	Operations Squadron	= 130 per Base	130
	Maintenance Personnel (b through e)		6441
	Line Personnel (a through g)		10404
h.	Civil Engineering Sqdn.	= Curve Value	1029
i.	Air Police Squadron	= Curve Value	310
j.	Service Squadron	= Curve Value	340
k.	Supply Squadron	= Curve Value	1143
l.	Transportation Sqdn.	= Curve Value	333
m.	Dispensary	= Curve Value	346
n.	Air Transp. Wing Command	= 80 per Base	80
o.	Air Base Group	= 8.8% (a through n)	1234
	Military Personnel	= Base Personnel (a through o) ÷ 1.20	13019
	Pilots	= Pilots/Crew x Crew/Airpl. x Nw	338
	Navigators	= Nav./Crew x Crews/Airpl. x Nw	224
	Non-Crew Officers	= 1/23 of (b through o) + 50% Air Transp. Sqdn. Ovhd.	668
	Airmen	= Military Pers. - Total Officers	11792
	Civilian Personnel	= 20% of Total Military Personnel	2604
	Total Base Personnel (a through o)		15623

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Table 39 Total Program Costs For Ship Fleets (All Costs In Millions of Dollars)

SHIP	WEIGHT LIMITED PAYLOADS		SPACE LIMITED PAYLOADS FOR DEPLOYMENT OF ARMORED DIVISIONS	
	No. Required	Total 10 Year Program Cost	No. Required	Total 10 Year Program Cost
C4-S-1a	13	312.754	10	240.580
C4-S-57a	11	263.142	12	287.064
C3-S-A2	17	328.984	10	193.520
C2-S-AJ1	20	314.120	14	219.884
VC2-S-AP3	19	311.068	17	278.324
C1A	31	399.280	17	218.960
742-320S	9	264.150	9	264.150
742-321S	6	355.620	3	177.810
C1-M-AV1	49	496.370	-	-
C4-ST-67a	17	439.960	11	284.680
C3-ST-14a	20	424.000	12	254.400
T2-SE-A1	8	102.624	-	-

DAYS AT SEA: Cargo ships with conventional cargo handling gear 200 days
Cargo ships with advanced cargo handling gear 238 days
Tankers 280 days

in present dollars since DOD makes cost effectiveness comparisons on this basis.

The fleet size required to perform any given deployment task is dependent on utilization, speed, capability and characteristics of the particular ship. However, the cost involved in performing the wartime deployment is not calculated because the significant budget considerations are the peacetime costs for a wartime capability. Also, the costs of a major war are indeterminate because of size, length and location considerations. Occasional limited wars may cost little compared to the year-in year-out costs of peacetime preparedness. The program cost represents the expenditures of acquiring the desired force and operating and maintaining it over a given time period under peacetime conditions. MSTS ships are assumed to have a program life of 25 years per Public Law 86-518 (1960).

8.2.2 PROGRAM COST

Since the primary purpose of this document is to compare surface and air deployment costs, a ten year program cost will be used. This is the time period assumed for MATS transports. MSTS ships have a 25 year life and, therefore, the ship Initial Cost will be prorated for a ten year period and added to ten years of Annual Operating Expense.

8.2.3 INITIAL COST

The Initial Cost for a ship is taken as the complete delivery price of the ship. For air transport costing, the complete delivery price of the airplane is only 40 percent to 70 percent of the total Initial Investment Cost. The additional aircraft Initial Investment Cost items are listed below with a brief explanation as to why a similar allowance was not made for ship Initial Cost.

Command Support Aircraft - The ship and crew are assumed to have a 10 day lay-up period annually for maintenance and repair, so there is no requirement for command support ships.

Advanced Attrition Buy - Peacetime attrition of ships is assumed to be negligible.

Maintenance Spares - Spare parts for conventional ships are not as specialized as spare parts for

aircraft. For this application, it is assumed that the cost of the initial on board stock of maintenance parts is included in the complete delivery price of the ship.

<u>Personnel Training and Transportation</u> - For MSTS most training is inherited or gained on the job and there are training and travel allowances in the annual Overhead Cost for MSTS.

<u>Base Costs, AGE, Stocks POL, and Non Aircraft Supply</u> - No allowance is made for any of these items because the ship's port is assumed to exist and little, if any, modification is required to accommodate the new conventional ship.

Similarly, it is not considered necessary to purchase special handling equipment (corresponding to AGE), stocks of POL, non-ship supplies or other items which are assumed to be inherited with the port.

The complete delivery price of the ship is estimated as a function of the cubic number (CN) and the normal shaft horsepower (SHP_N). Reference suggests that one of the best measures of overall ship size is CN which is defined as follows: CN = LBD/100. L = length between perpendiculars, B = beam or breadth and D = depth (including freeboard).

The hull cost is estimated as a function of CN with variations as to the complexity of the outfitting. See Fig. 117. The cost line labeled TYPICAL - AVERAGE PASSENGER, NO REEFER is used unless a specific outfitting is requested for cargo ships.

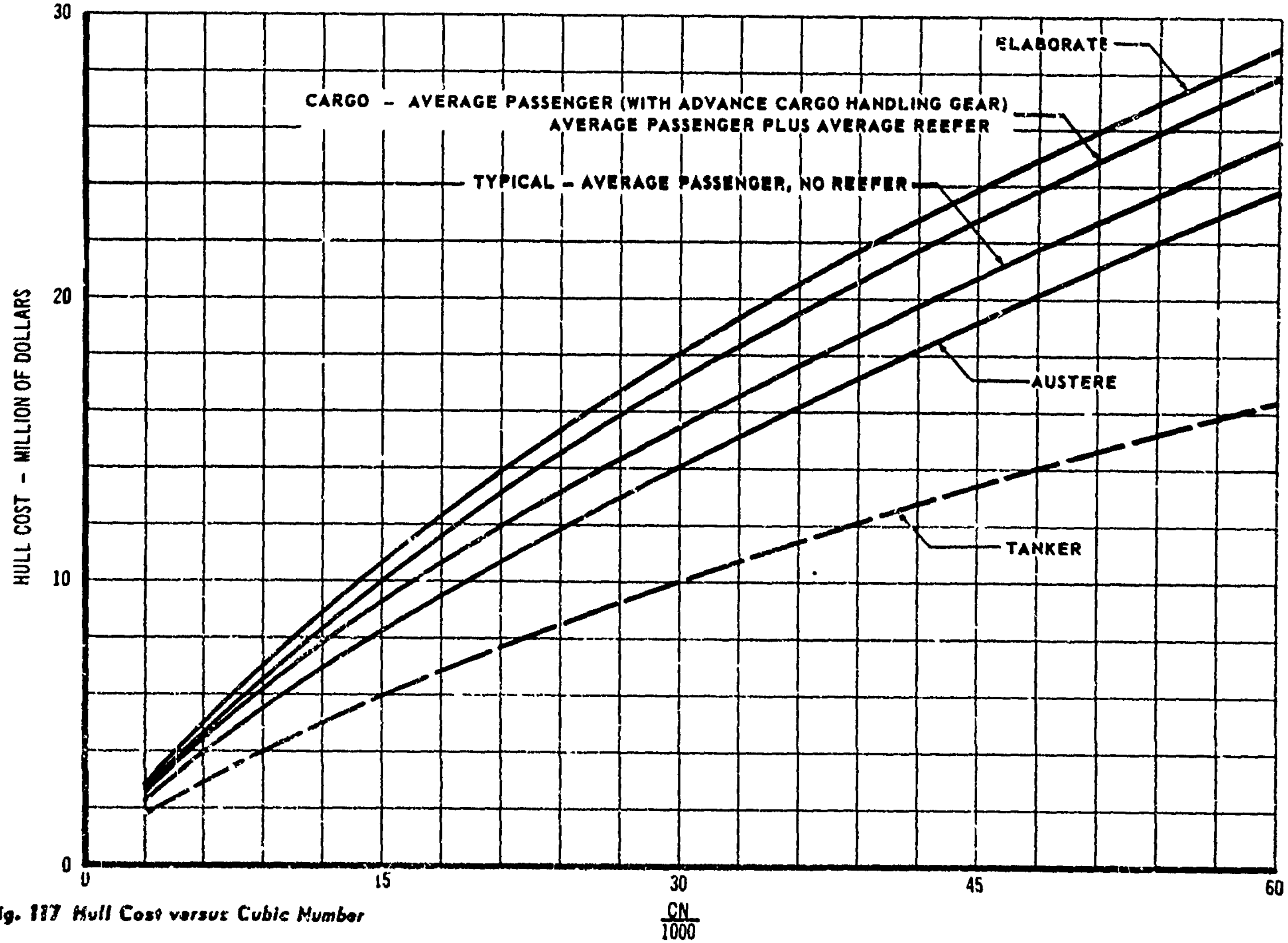

Fig. 117 Hull Cost versus Cubic Number

The machinery cost is estimated as a function of SHP_N with machinery located either amidship or aft. See Fig. 118.

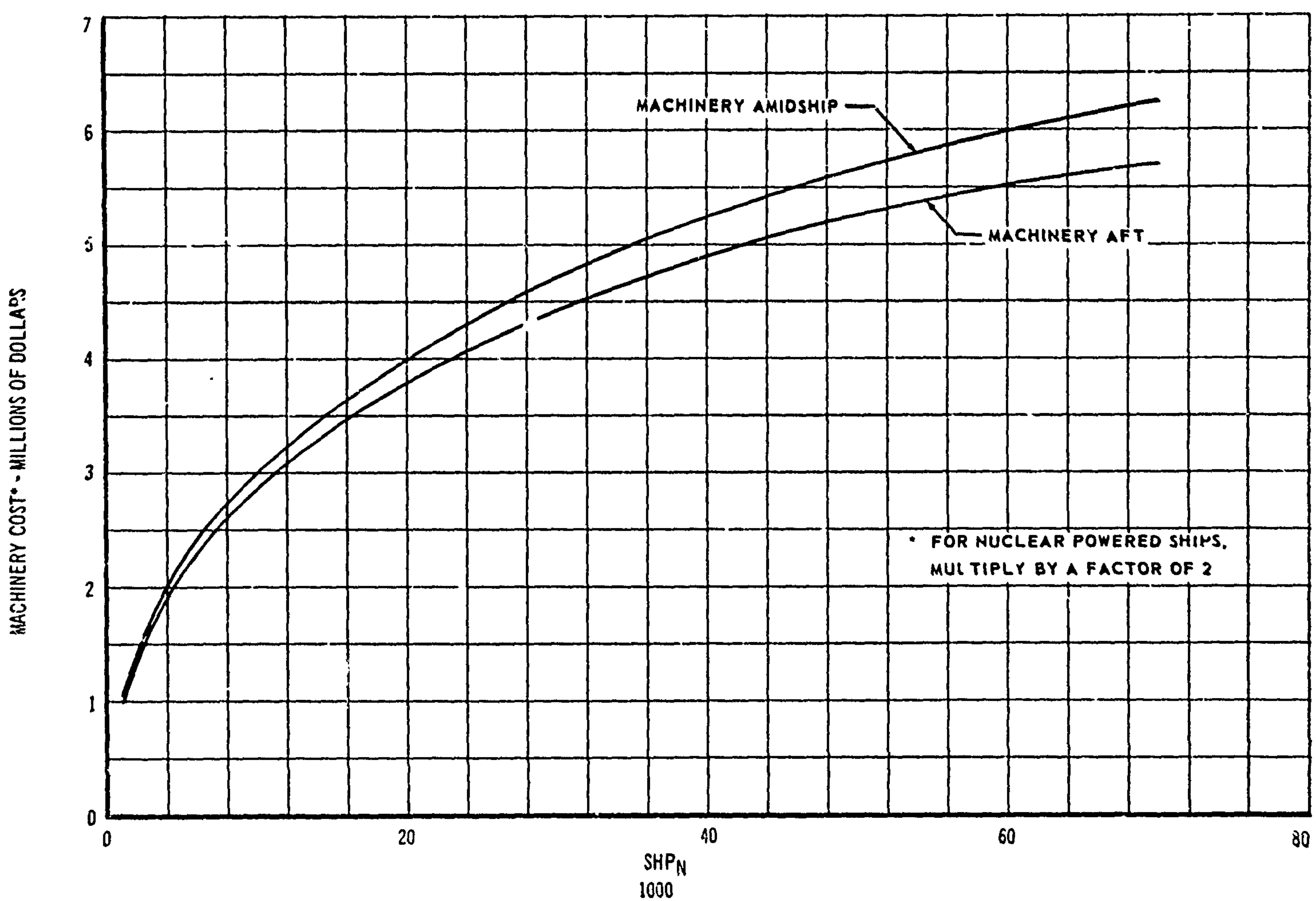

Fig. 118 Machinery Cost versus Shaft Horsepower Normal

The Initial Cost is the sum of hull cost and machinery cost. A sample calculation of the Initial Cost of a conventional cargo ship is given in Table 40. The Initial Cost of a ship is assumed to be the construction cost (bid price) plus additional costs for inspection and items added by the owner. Ref. 27 estimates these additional costs as eight percent of the construction cost.

8.2.4 ANNUAL OPERATING EXPENSE

Annual Operating Expense represents the expenditures directly connected with the peacetime operations and maintenance of a ship. The cost categories itemized below conform to the reporting method used in MSTS Financial and Statistical Reports plus the Cargo Handling Costs. Each of these categories is explained on later pages. For comparison, the categories used in estimating Annual Operation and Maintenance Costs for MATS aircraft are also shown.

Table 40

INITIAL COST AND ANNUAL OPERATING EXPENSE OF MSTS SHIPS (IN MILLIONS OF $)

SHIP MODEL C4-S-1a
OUTFIT COMPLEXITY Typical W/Reefer
MACHINERY Steam Turbine
LOCATION Amidships

L = LENGTH BET. PERP.	= 528	SHP_N OR BHP_N = 17,500
B = BEAM	= 76	T_s = DAYS AT SEA/YR = 200
D = DEPTH TO UPPERMOST CONT. DECK	= 44.5	D_v = VOYAGE DISTANCE = 16,000
CN = CUBIC NUMBER = $\frac{LBD}{100}$	= 17,857	N_v = NUMBER VOYAGES = $\frac{24 T_s V_s}{D_v}$ = 6
V_s = SUSTAINED SEA SPEED	= 20K	BALE CAPACITY, CU FT = 737,000

I. INITIAL COST	
A. HULL COST	11.550
B. MACHINERY COST	3.770
DELIVERY PRICE (A+B)	15.320
II. ANNUAL OPERATING EXPENSE	
A. MAINTENANCE AND REPAIR	
HULL AND OUTFIT	.081
MACHINERY	.042
B. CREW PAY AND SUBSISTENCE	.700
C. FUEL COST: SEA FUEL	.279
PORT FUEL	.021
D. PORT CHARGES	.031
E. SUPPLIES, EQUIPAGE, AND OTHER COSTS	.343
F. OVERHEAD COST = .027 (A through E) 1.456	.039
G. CARGO HANDLING COST	
CARGO SHIP = .3 (BALE CAPACITY/40) ($9.00/MT) ($N_v$)	.398
TANKER NO CHARGE	
ANNUAL OPERATING EXPENSE PER SHIP (A through G)	1.793

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Annual Operating Expense

Ships	Aircraft
Maintenance and Repair	Maintenance and Repair
Crew Pay and Subsistence	Personnel Pay and Allowances
	Replacement Training and Personnel Transportation
Fuel Costs	Aircraft POL
Port Charges	Base Maintenance
Supplies, Equipage and other Costs	Miscellaneous Costs
Overhead Cost	
Cargo Handling Costs	

The operating assumptions used for estimating annual costs are given below.

	CARGO SHIPS		TANKERS
	Conventional	With Adv. Cargo Handling Gear	
Days/Year Underway	200	238	280
Days/Year in Port	155	117	70
Days/Year Lay-up Time	10	10	15
Average N.Mi. between Ports	1500	1500	1500

Table 40 shows a sample calculation of Annual Operating Expense for a cargo ship.

- Maintenance and Repair

This item(Figs. 119 and 120) consists of the labor and material necessary for the annual lay-up as well as the material used in routine maintenance. The maintenance and repair costs for the hull are related to the size factor - CN, while the machinery costs are related to the normal shaft horsepower - SHP_N.

- Crew Pay and Subsistence

The number in the crew and the average pay is estimated (Fig. 121) as a function of ship size (CN) and its machinery (SHP_N). These data were calculated from Ref. 27 for dry cargo ships and Ref. 28 for conventional tankers.

The crew sizes in Fig. 121 do not include the extra crew members required when passengers are carried. One crew member is added for every five passengers and the cost is increased by the ratio of extra crew members over the number in a standard crew.

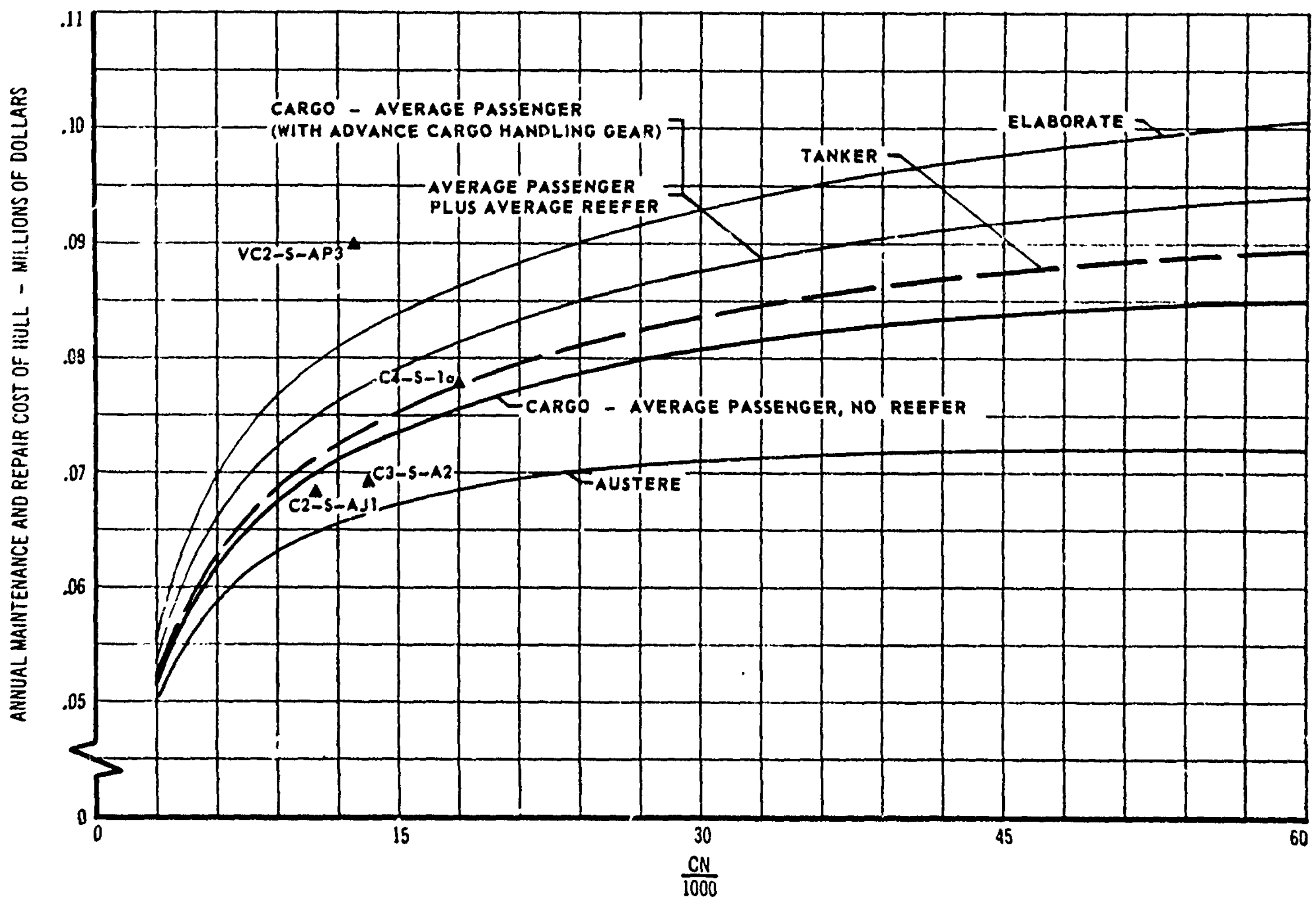

Fig. 119 Hull Maintenance and Repair versus Cubic Number

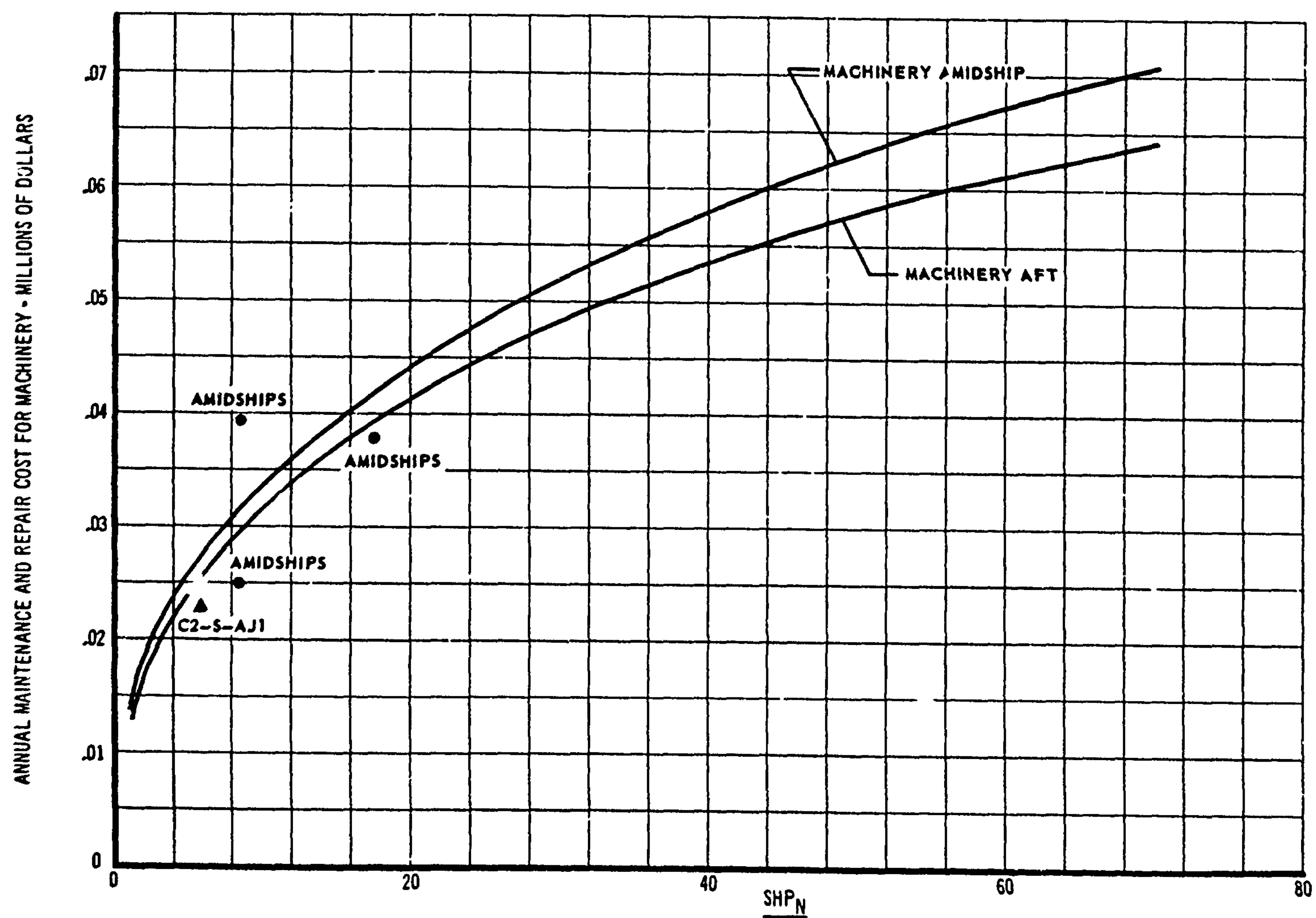

Fig. 120 *Machinery Maintenance and Repair versus Shaft Horsepower Normal*

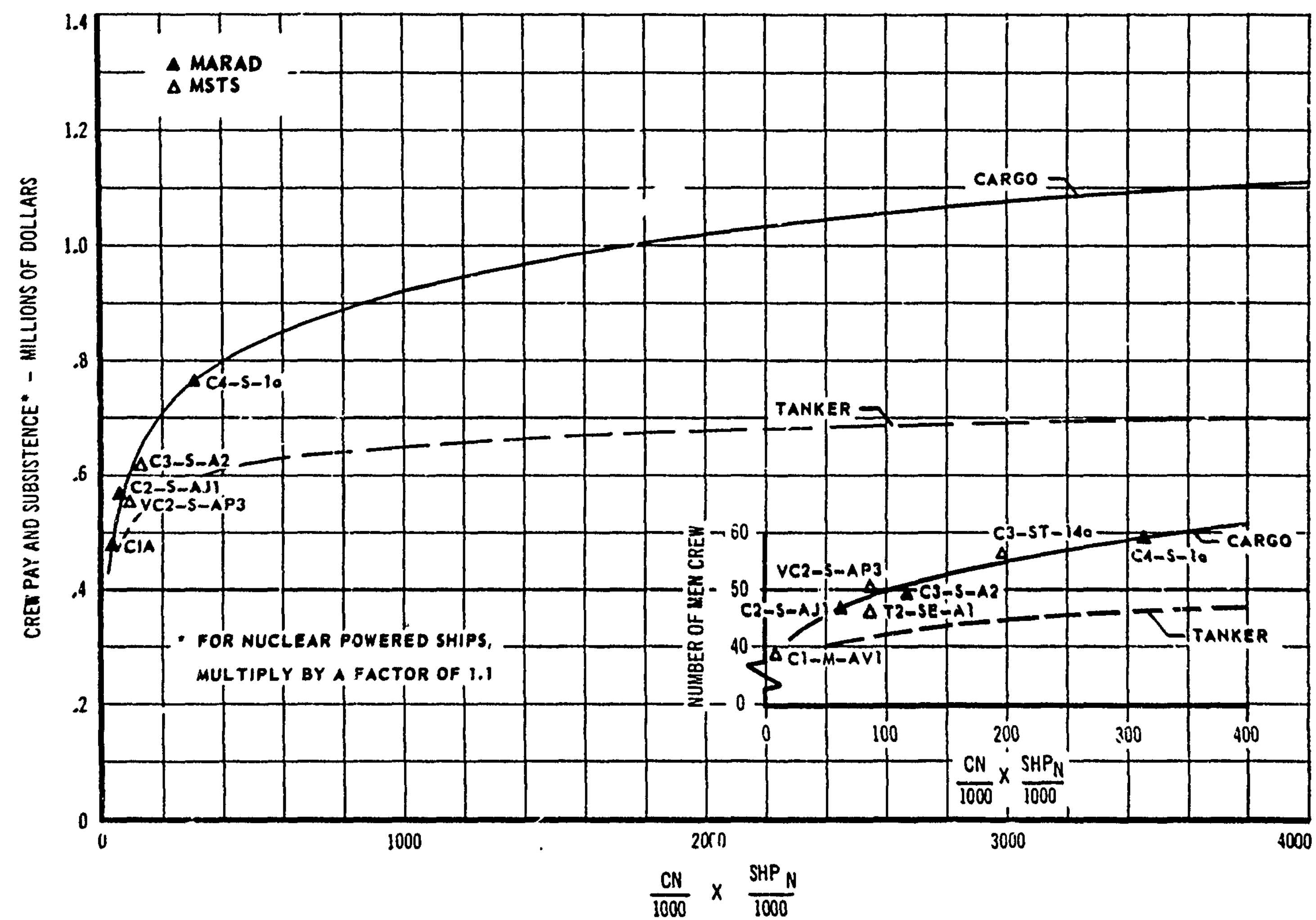

Fig. 121 Crew Pay and Subsistence versus Cubic Number x Shaft Horsepower Normal

- Fuel Costs

  The annual cost for fuel (Figs. 122 and 123) is estimated as a function of SHP_N for underway fuel and as the product (CN) (SHP_N) for port fuel necessary to provide hotel services for the crew. The price of Bunker C fuel used was $2.15 per barrel while diesel fuel was priced at $3.60 per barrel.

- Port Charges

  Port charges (Fig. 124 depend primarily on the registered tonnage of the ship but the standard size factor (CN) was used for estimating these costs. The estimates are based on data from the MSTS PAC Financial and Statistical Reports. Since MSTS ships are often berthed at military terminals where port costs do not apply, the estimated cost for port charges will be too low for commercial cargo ships.

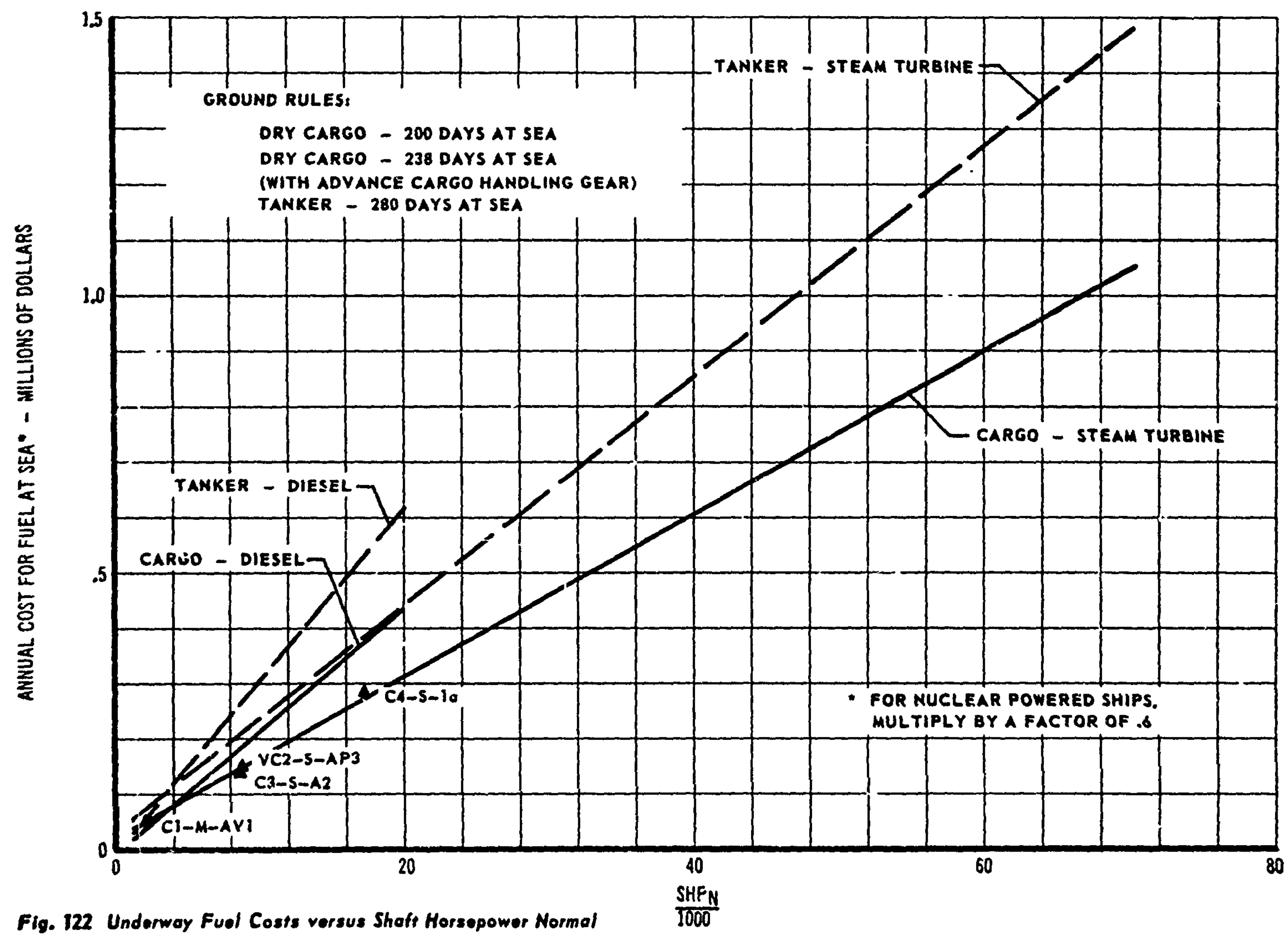

Fig. 122 Underway Fuel Costs versus Shaft Horsepower Normal

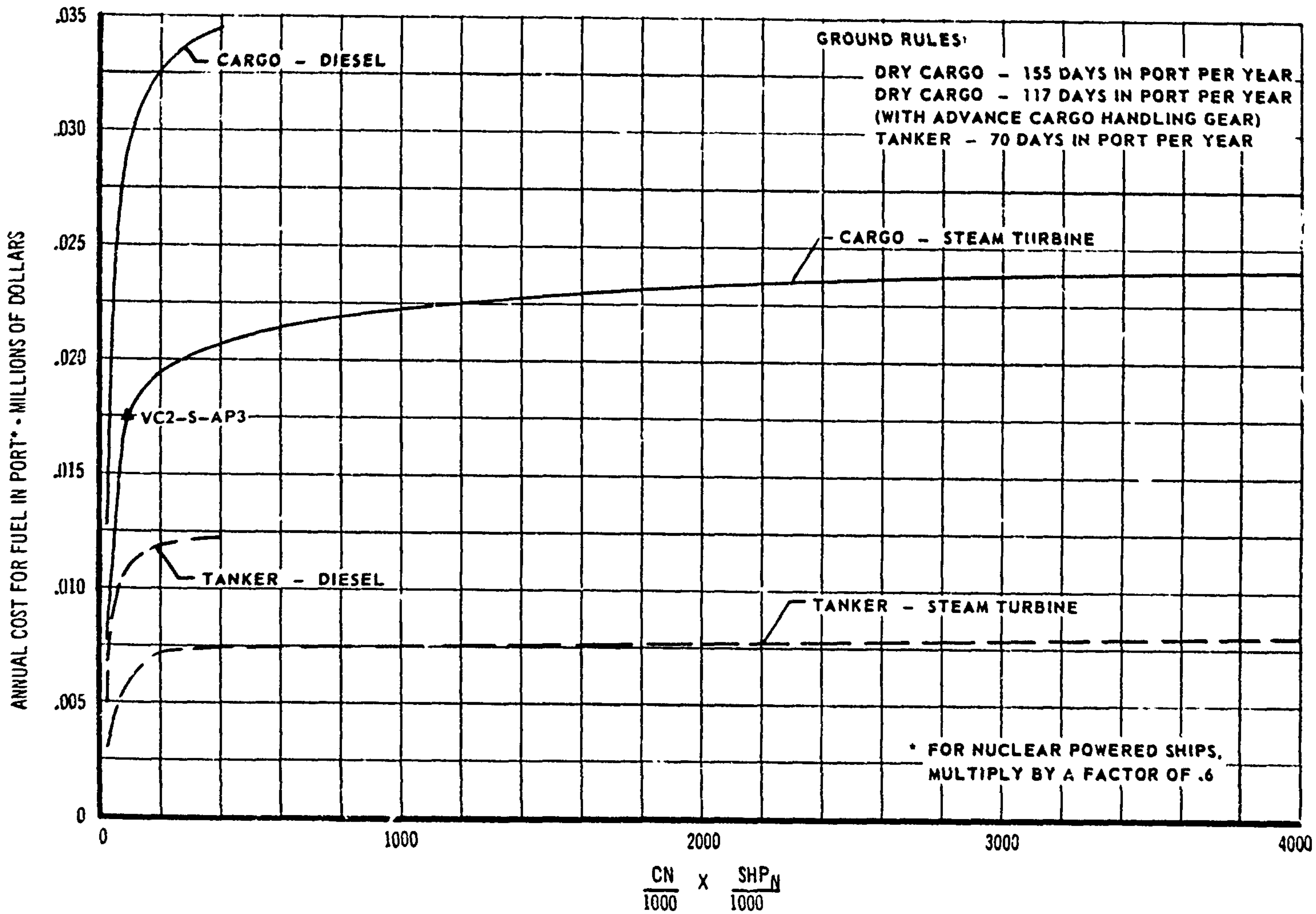

Fig. 123 Port Fuel Cost versus Cubic Number x Shaft Horsepower Normal

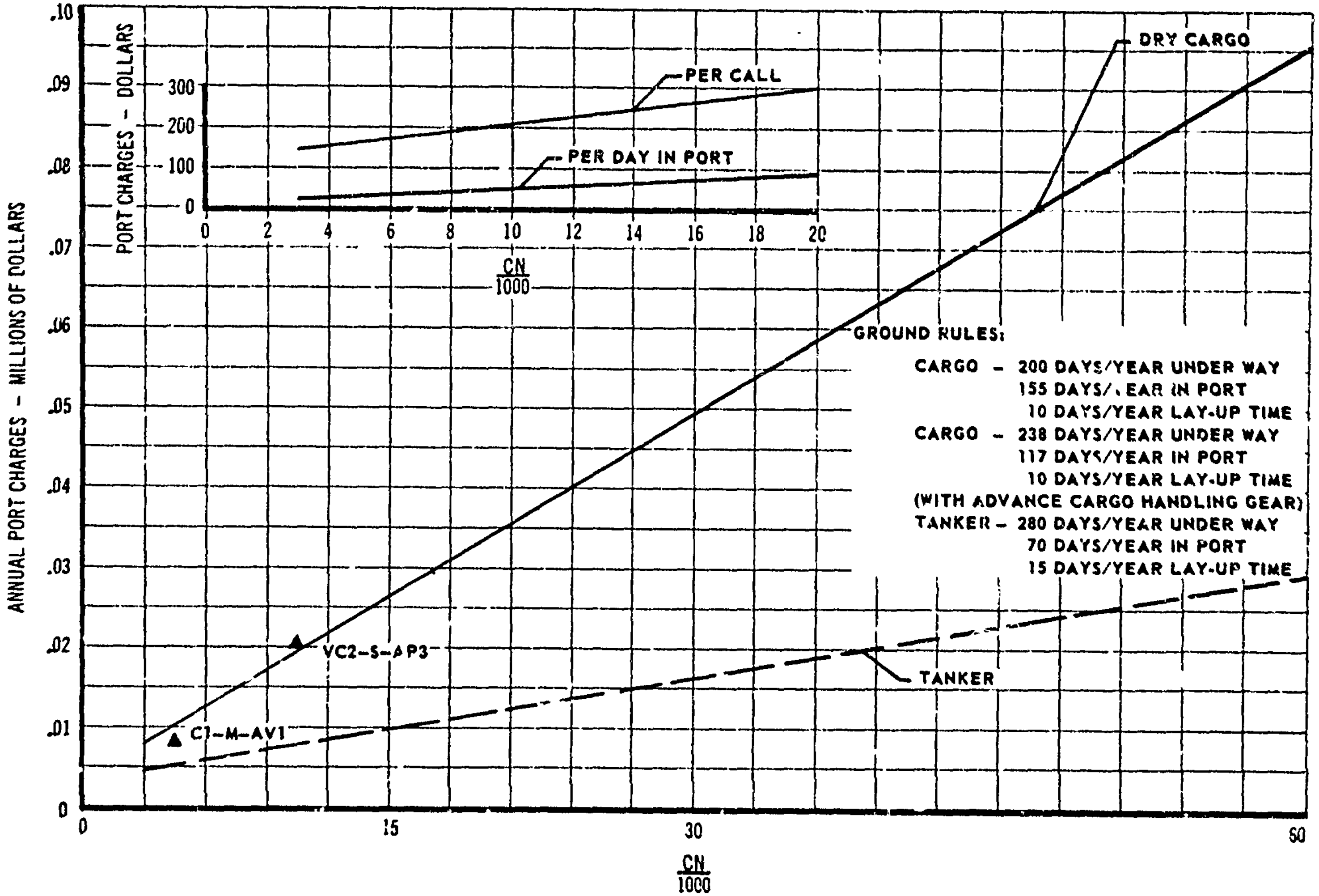

Fig. 124 Port Charges versus Cubic Number

- Supplies, Equipage and Other Costs

  These costs depend on ship size, number of crew and amount of ship activity. Therefore, (CN) (SHP_N) is used as the parameter to estimate these costs. (See Fig. 125).

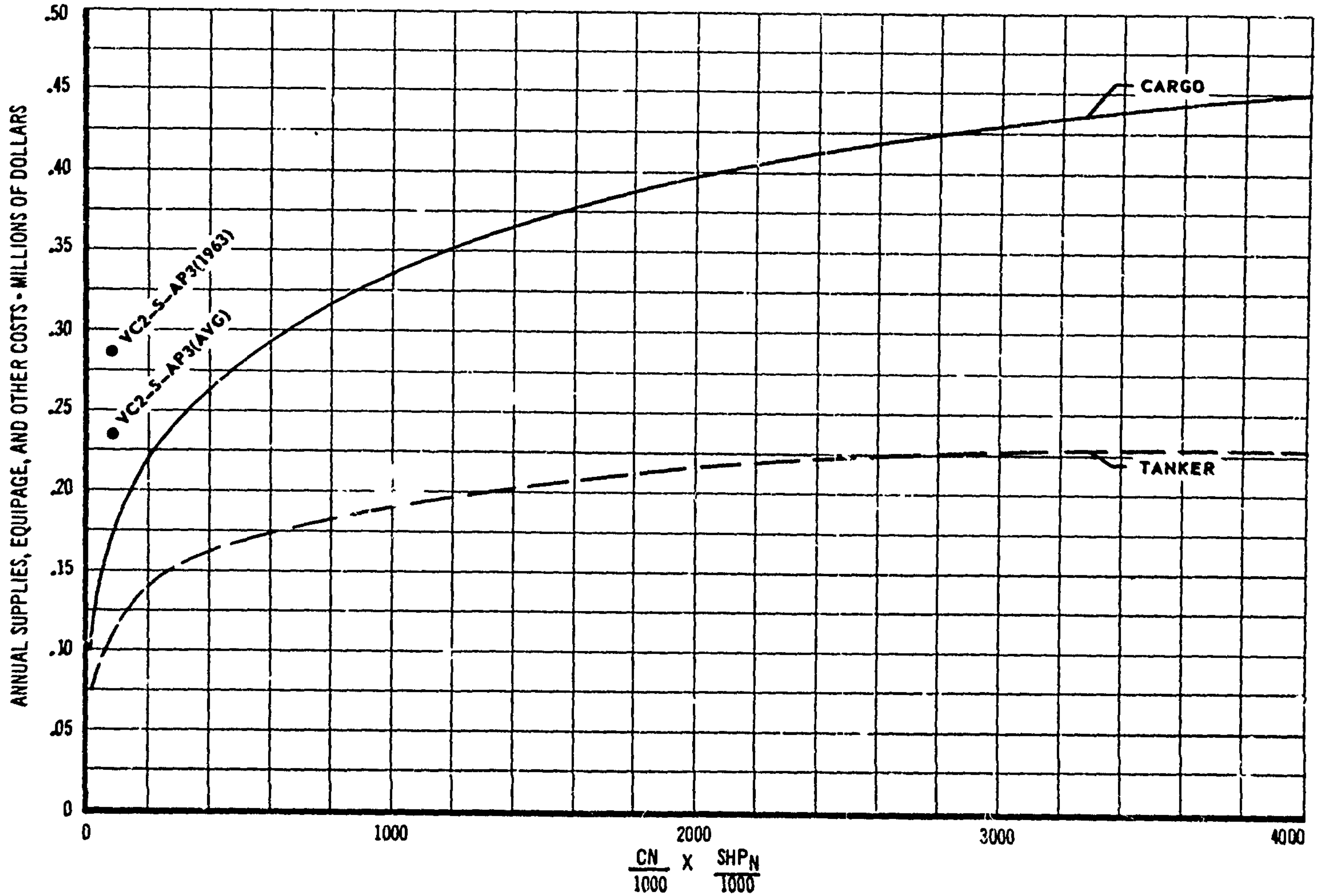

Fig. 125 Supplies, Equipage, and Other Costs versus Cubic Number x Shaft Horsepower Normal

- Overhead Costs

  This item covers a specific ship's share of the MSTS base operating expenses. It includes salaries, indoctrination costs, training and travel costs, and expenses for supplies, communications and occupancy of premises. Overhead Costs are estimated as 2.7 percent of Annual Operating Expense items A through E.

- Cargo Handling Costs

  The Terminal Cargo Trans-shipment rates as given in U.S. Army Supply and Maintenance Command SMC PAM No. 55-1 (1963) were averaged for Pacific ports to estimate the average cost for cargo handling per measurement ton. The bale capacity of a ship is divided by 40 to obtain measurement tons and a 30 percent load factor is assumed. The terminal costs for tankers is included in the cost of fuel being transported.

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The information is presented in data plots for ease of comparison and summarized in tables. Most coverage is given to current and possible future transport aircraft and ships. These future vehicles are projected to 1983. Covered in smaller numbers are airships, helicopters, ground effect machines, hydrofoils and submarines.

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Transport Vehicles
Efficiency Parameters
Cost Parameters
Operational Parameters
Aircraft
Ships
Submarines

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Contract No. NOw-63-0804C, Report No. D6-2067
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Data are shown for efficiency parameters such as vehicle L/D and for a cost parameter defined as the total transport system cost for each of the selected intercontinental transport vehicles. A section is presented on operational parameters which includes discussion of reliability, utilization, useful life and environment.

The information is presented in data plots for ease of comparison and summarized in tables. Most coverage is given to current and possible future transport aircraft and ships. These future vehicles are projected to 1983. Covered in smaller numbers are airships, helicopters, ground effect machines, hydrofoils and submarines.

Descriptors

Transport Vehicles
Efficiency Parameters
Cost Parameters
Operational Parameters
Aircraft
Ships
Submarines

UNCLASSIFIED